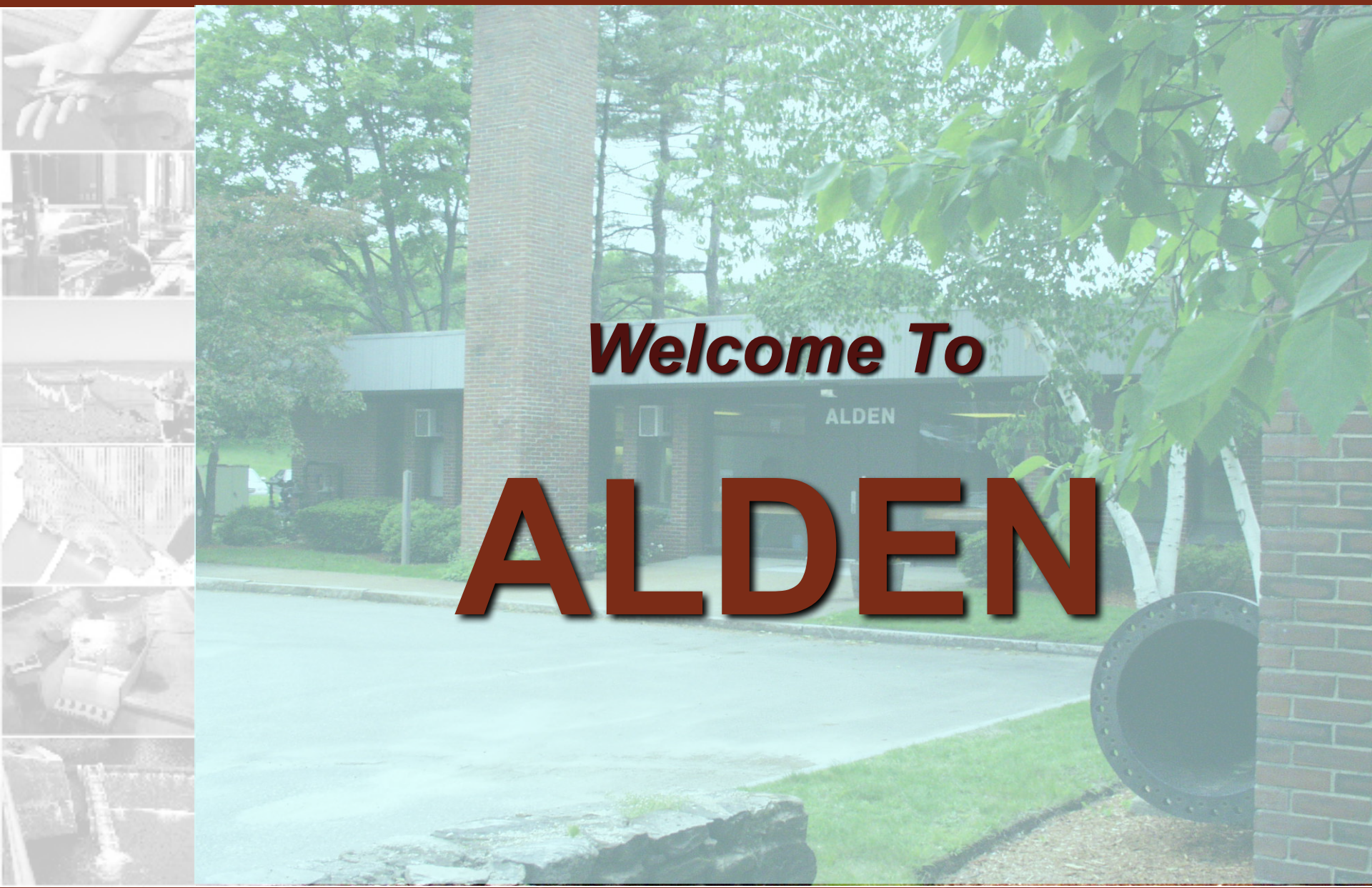
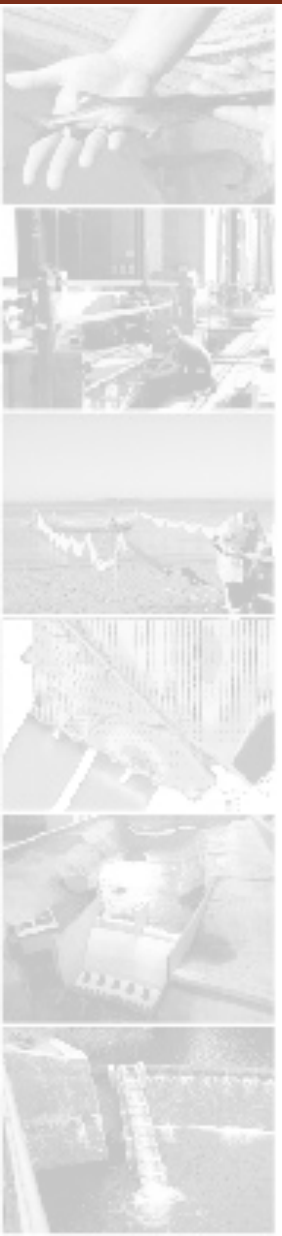


Welcome To

ALDEN



MODEL STUDY OF THE WALLER CREEK TUNNEL PROJECT

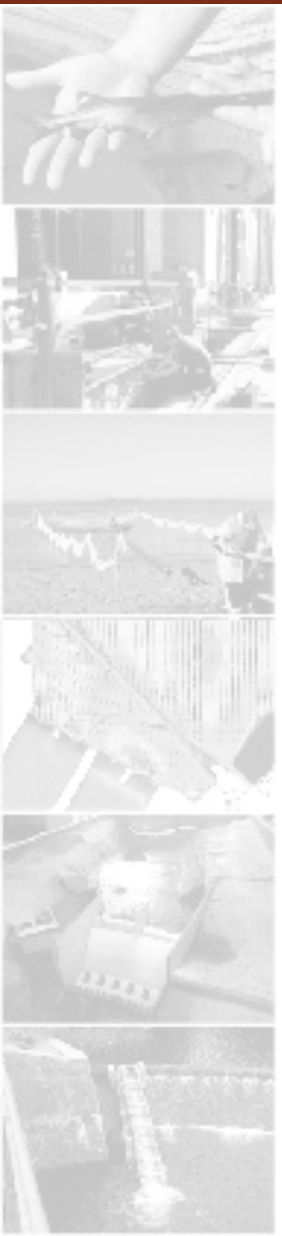
Presented to:

City of Austin

KBR / Espey Joint Venture

Brown & Gay Engineers

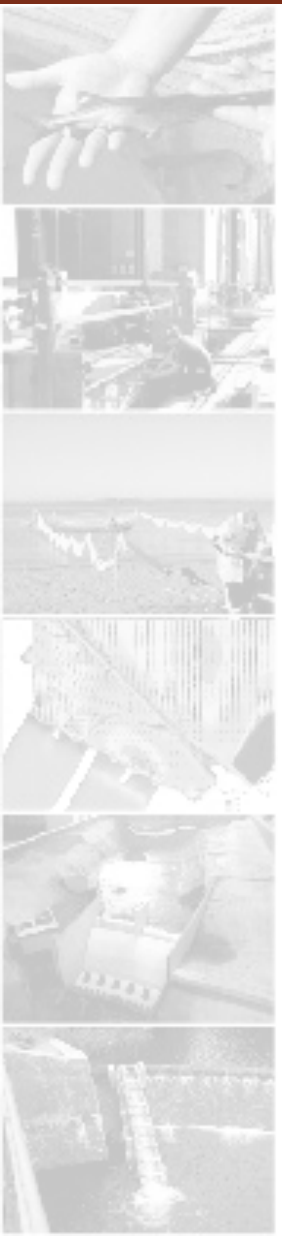
Crespo Consulting Services



Outline of Visit

Thursday July 8th

- Introductions 8:00-8:30
- Presentation
  - CFD Models 8:30-9:30
    - Inlet at Waterloo Park
    - Tunnel Lateral Junctions
    - Outlet
  - Physical Model Introduction 9:30 -9:45
- Model Demo 10:00-11:30
- Lunch 11:45-12:30
- Physical Model Results 12:30-1:30
- Model Demo 1:45-2:45
- Wrap-up Conclusions and Discussion 3:00-4:00



Outline of Visit

Friday July 9th

- Debrief 9:00
- Depart 12:00

Modeling Approach

- CFD Models
  - Detailed Evaluation of flow patterns in various structures
    - Velocity Distributions
    - Flow Splits
    - Flow Separations
    - Swirling Flow
  - Design Modifications are then incorporated into the physical models.

- Physical Model
  - Further Evaluation of flow patterns and phenomena which cannot be conducted using CFD.
    - Rating Curves (Water levels versus Flows)
    - Junction Losses
    - Vortexing
    - Air Entrainment
    - Fluctuating Pressures at Tunnel Portal

CFD Model Inlet at Waterloo Park

Objectives:

1. Conduct detailed assessment of the proposed design over a range of operating conditions:
   - Flow Patterns
   - Flow Velocities
   - Areas of Flow Separation
   - Flow Split Between Screens
   - Velocity Distribution Through Screens
2. Design modifications to improve any adverse hydraulic conditions.
3. Selection of a final design for further evaluation in the physical model.

CFD Model Inlet at Waterloo Park

Acceptance Criteria (Set by JV Team)

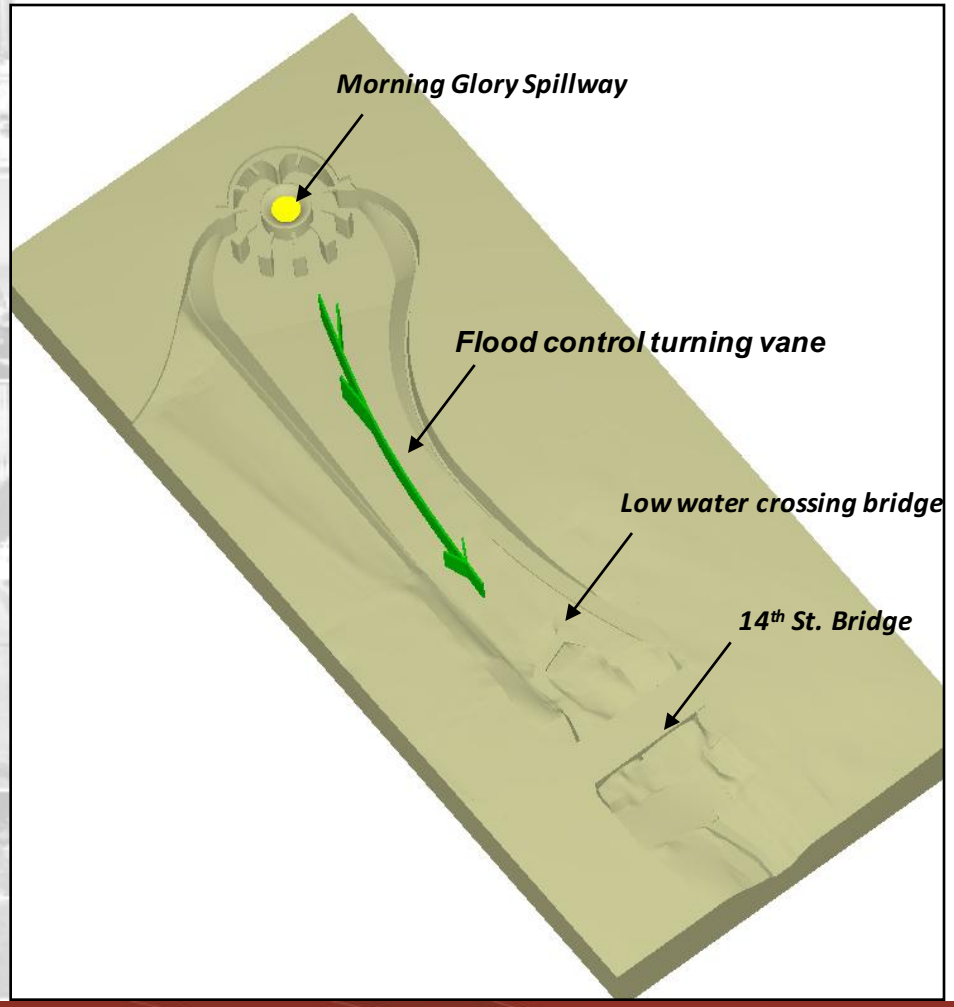
1. 80% of screen area below 4 ft/sec
2. Maximum allowable velocity in the screen area 5.5 ft/sec
3. Maximum allowable variation from the target flow is 50%

CFD Model Inlet at Waterloo Park

Modifications to the inlet/inlet pool:

1. By Joint Venture
   - Morning Glory Configuration, Number Of Screens
   - Topographic and Bathymetric Grading
2. By Alden
   - Flow Guidance Vanes and Training Structures

CFD Model Geometry and Flow Conditions



Flood Scenarios (Year)	Flows (cfs)
2	2,540
5	3,870
100	8,250
500	10,830

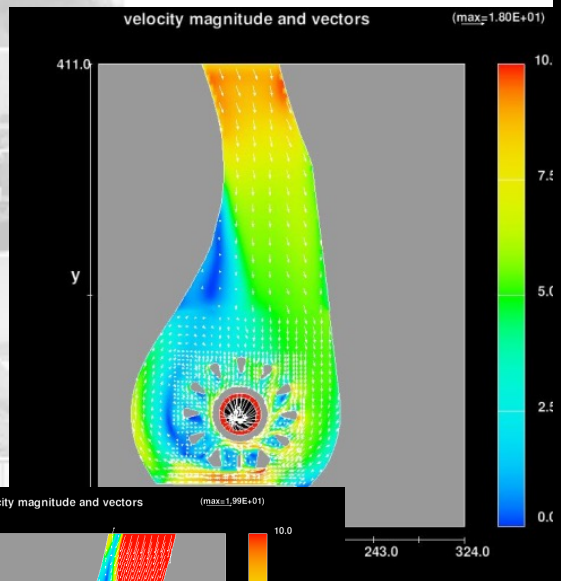
CFD Model Inlet at Waterloo Park

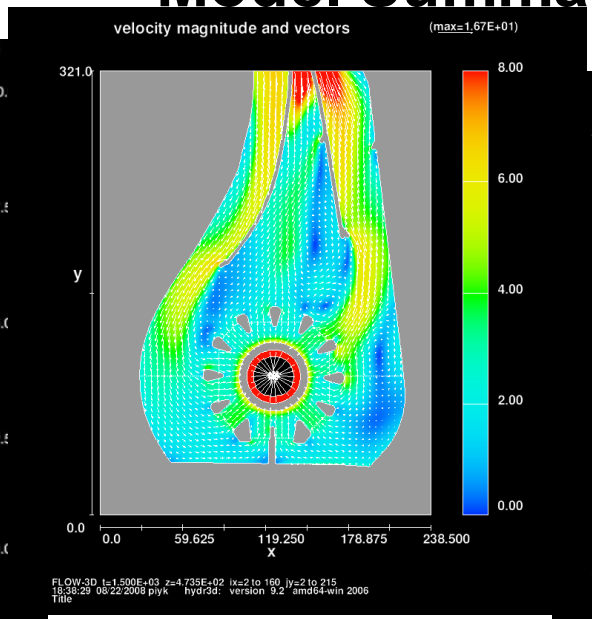
Model Summary

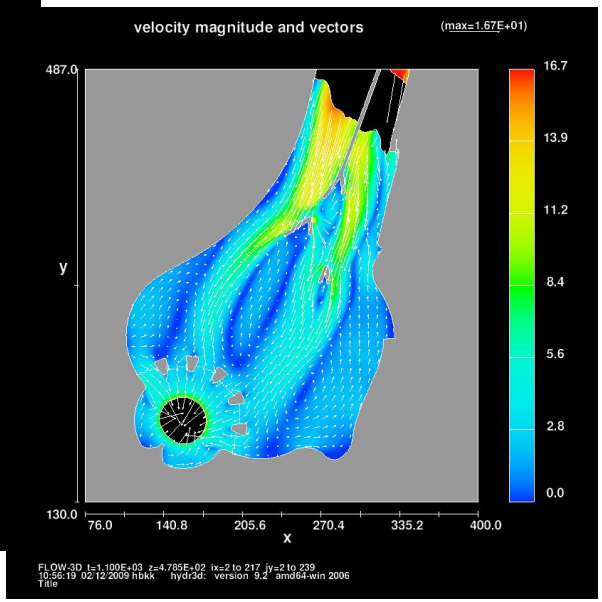
- **Developed in Flow 3D (Version 9.3) of Flow Science, Inc.**
- **Multiple mesh blocks with a total of about 2 million cells.**
- **One fluid (water) with free surface.**
- **Physics**
  - Unsteady flow (time-dependent)
  - Gravity driven flow
  - RNG turbulence model with no-slip wall boundary condition
- **Boundary conditions:**
  - Inflow
    - Upstream of 14th street bridge: specified flow at fixed water elevation.
  - Outflow
    - Morning glory spillway: mass sink

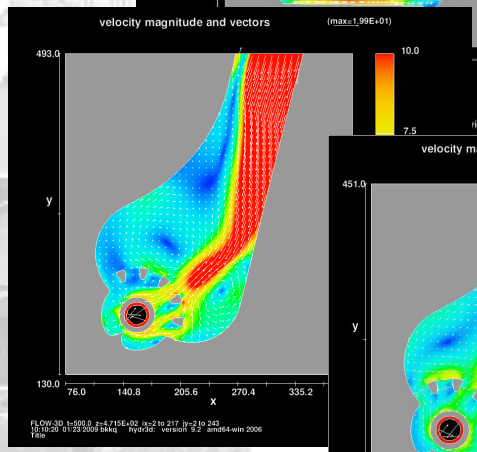
CFD Model Inlet at Waterloo Park

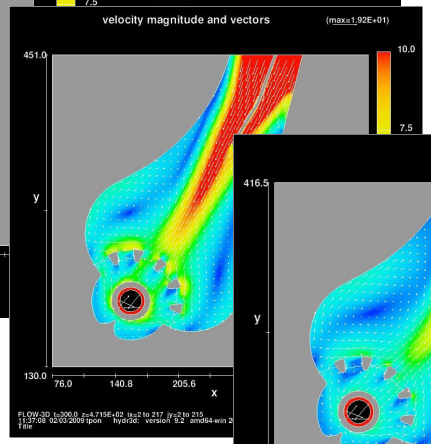
Model Summary

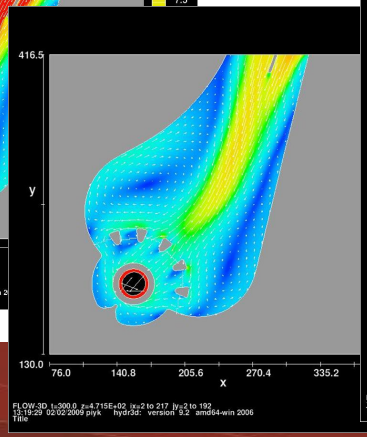


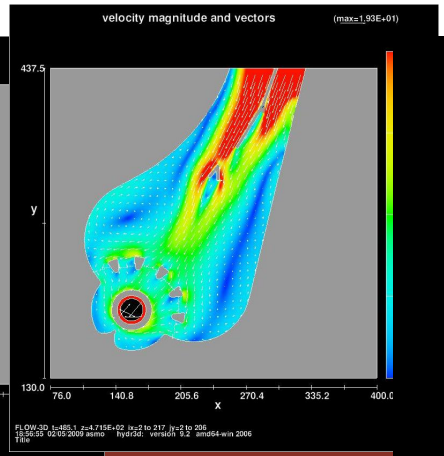


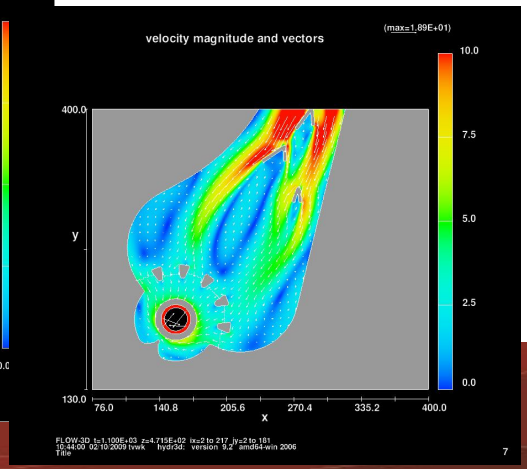










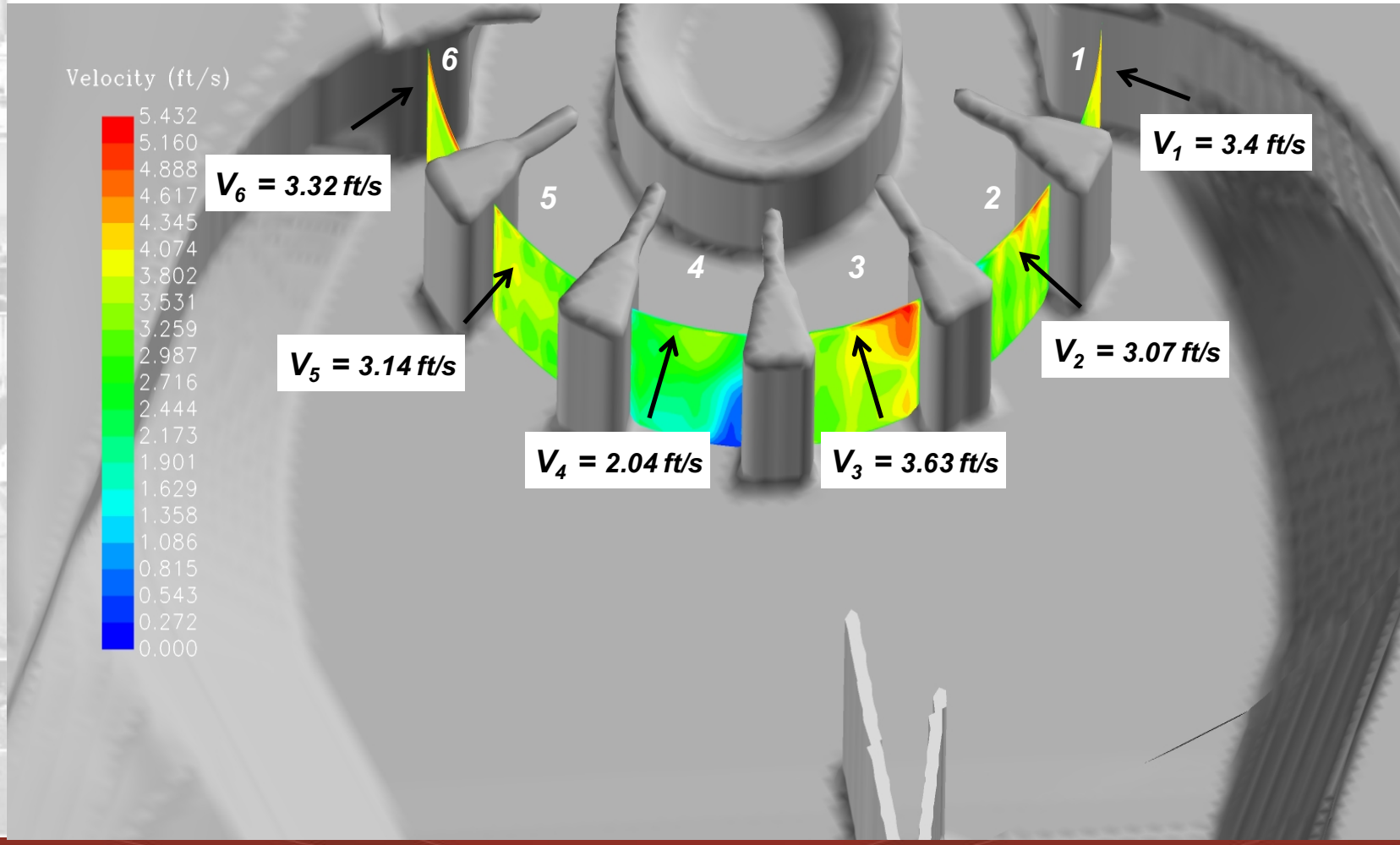


Average velocity (in the bar screen area)

(velocity color scale is the actual velocity)

Time = 2540 sec.

100 Year Flow Scenario

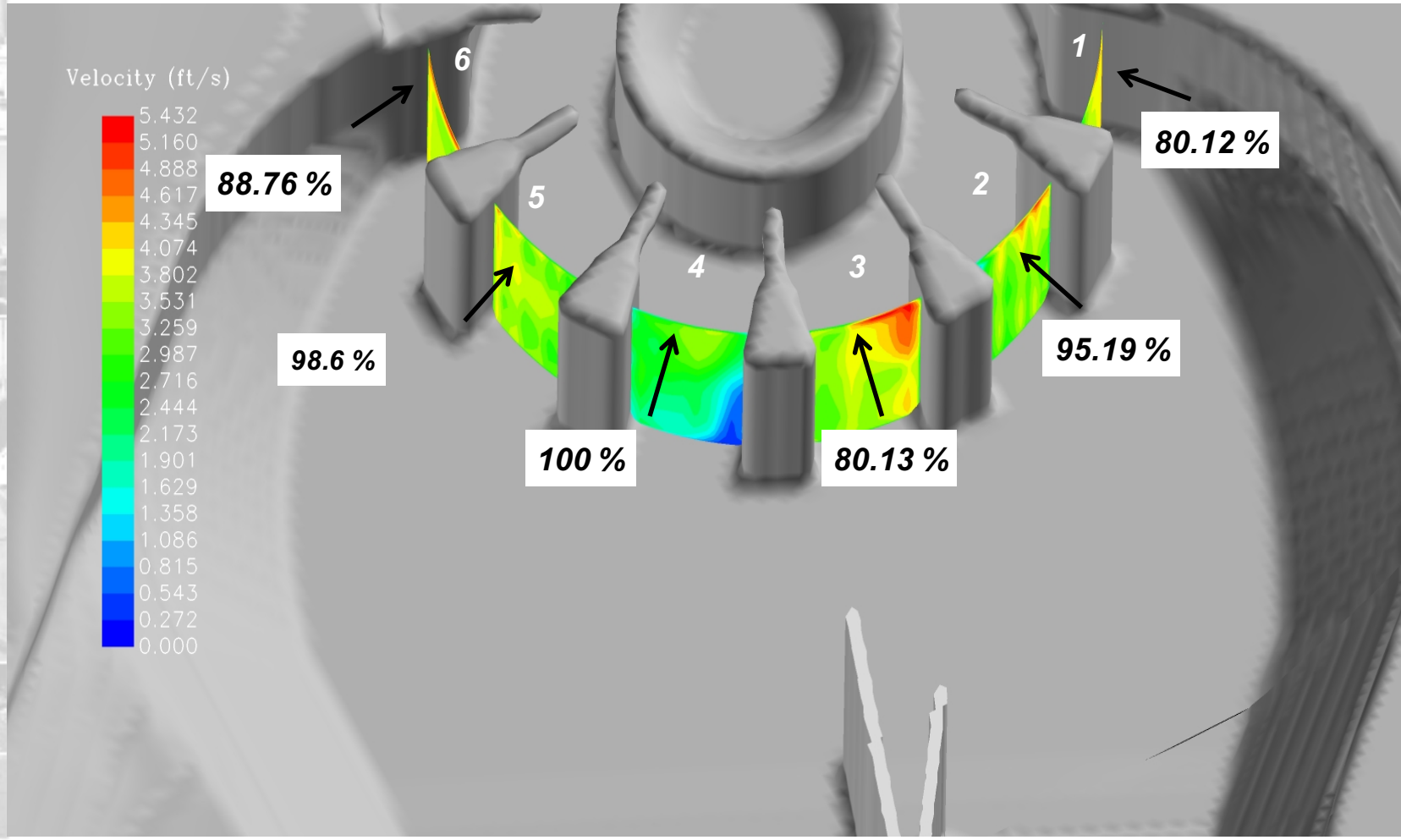


Percent of bar screen area at or below 4 ft/s

(velocity color scale is the actual velocity)

Time = 2540 sec.

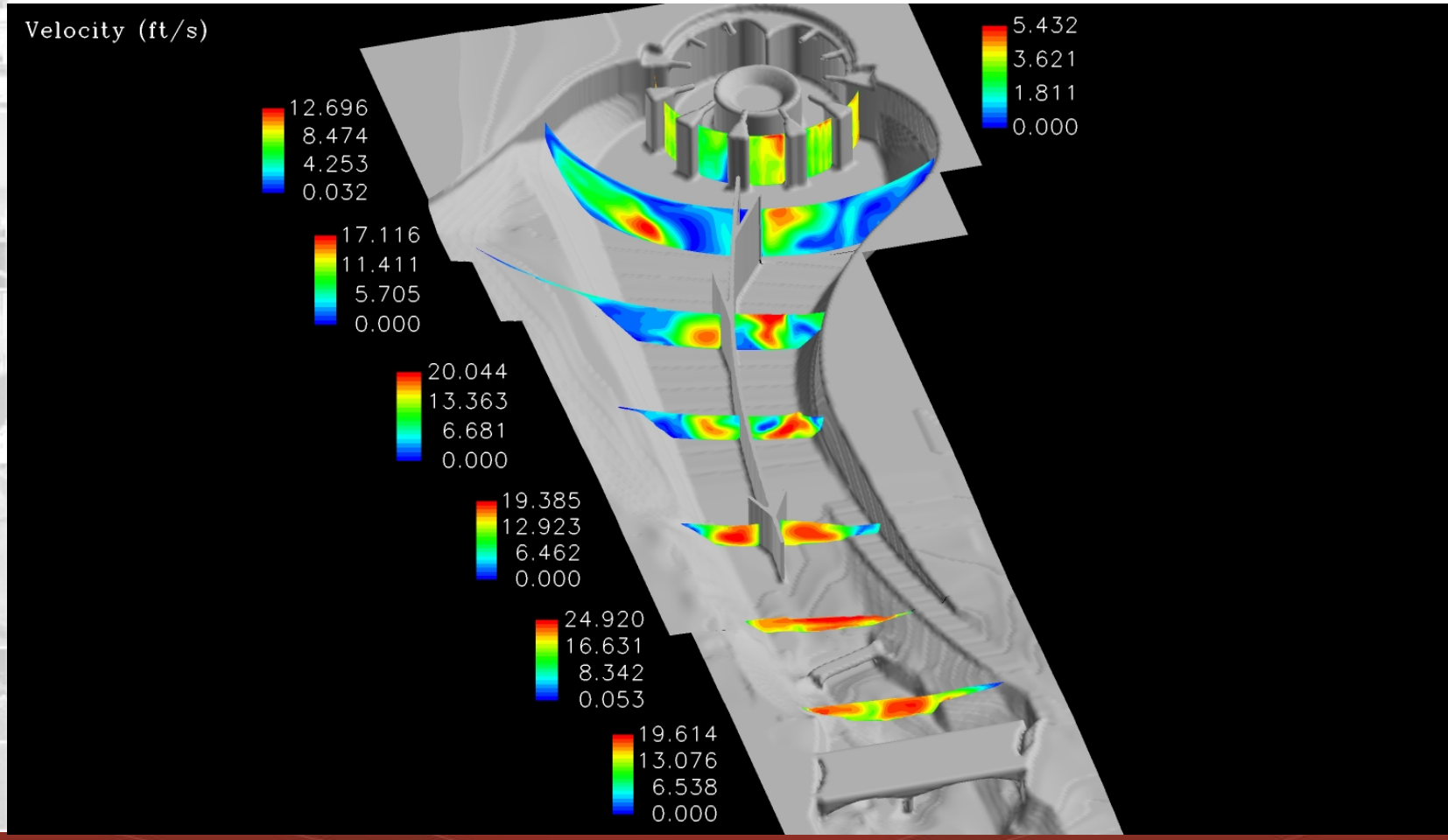
100 Year Flow Scenario



Velocity contour at different locations with different color scales

Time = 2540 sec.

100 Year Flow Scenario

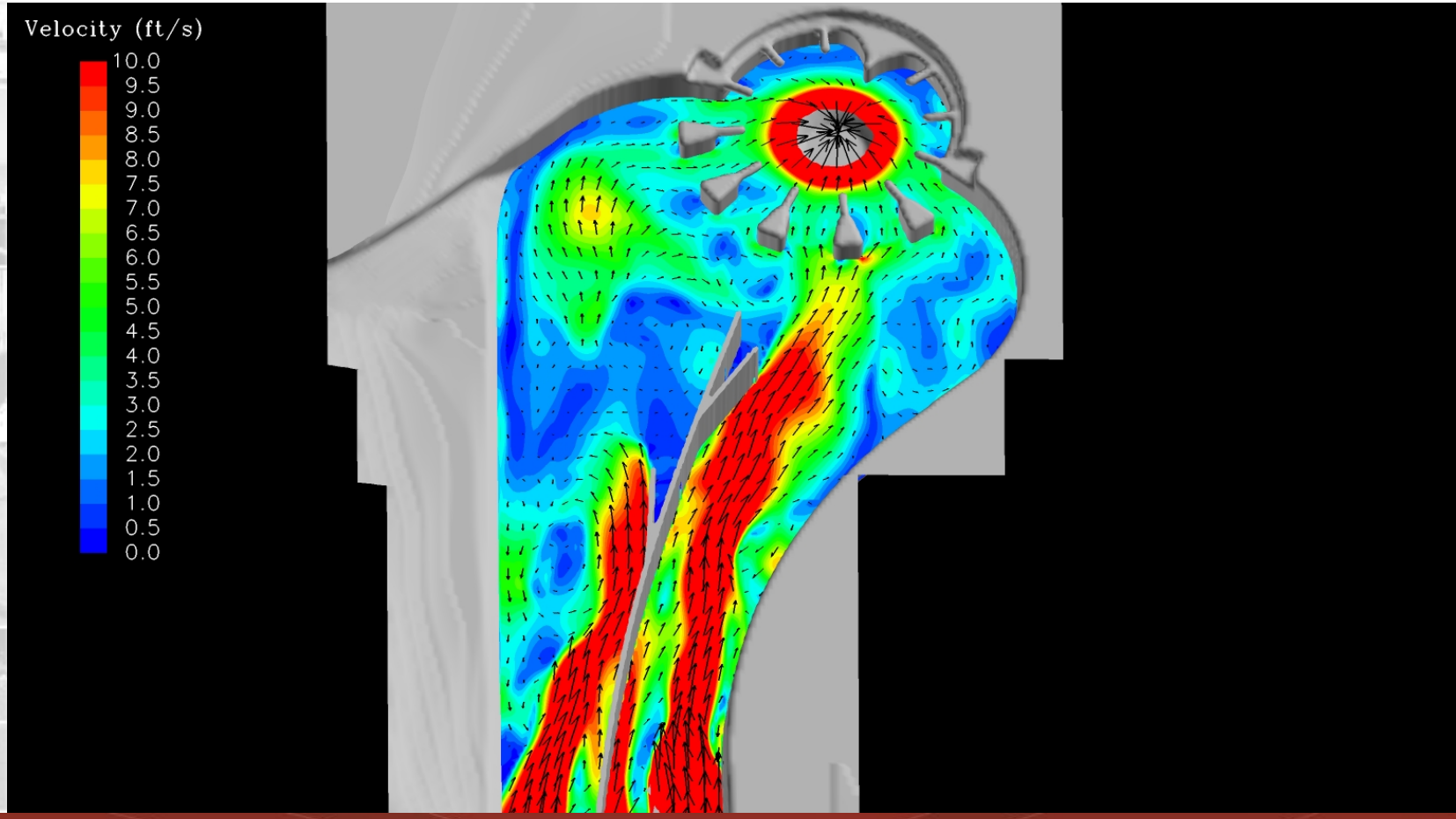


Plot of velocity contours with vectors
(slice plane cut at elevation 476 ft.)

Isometric View

Time = 2540 sec.

100 Year Flow Scenario

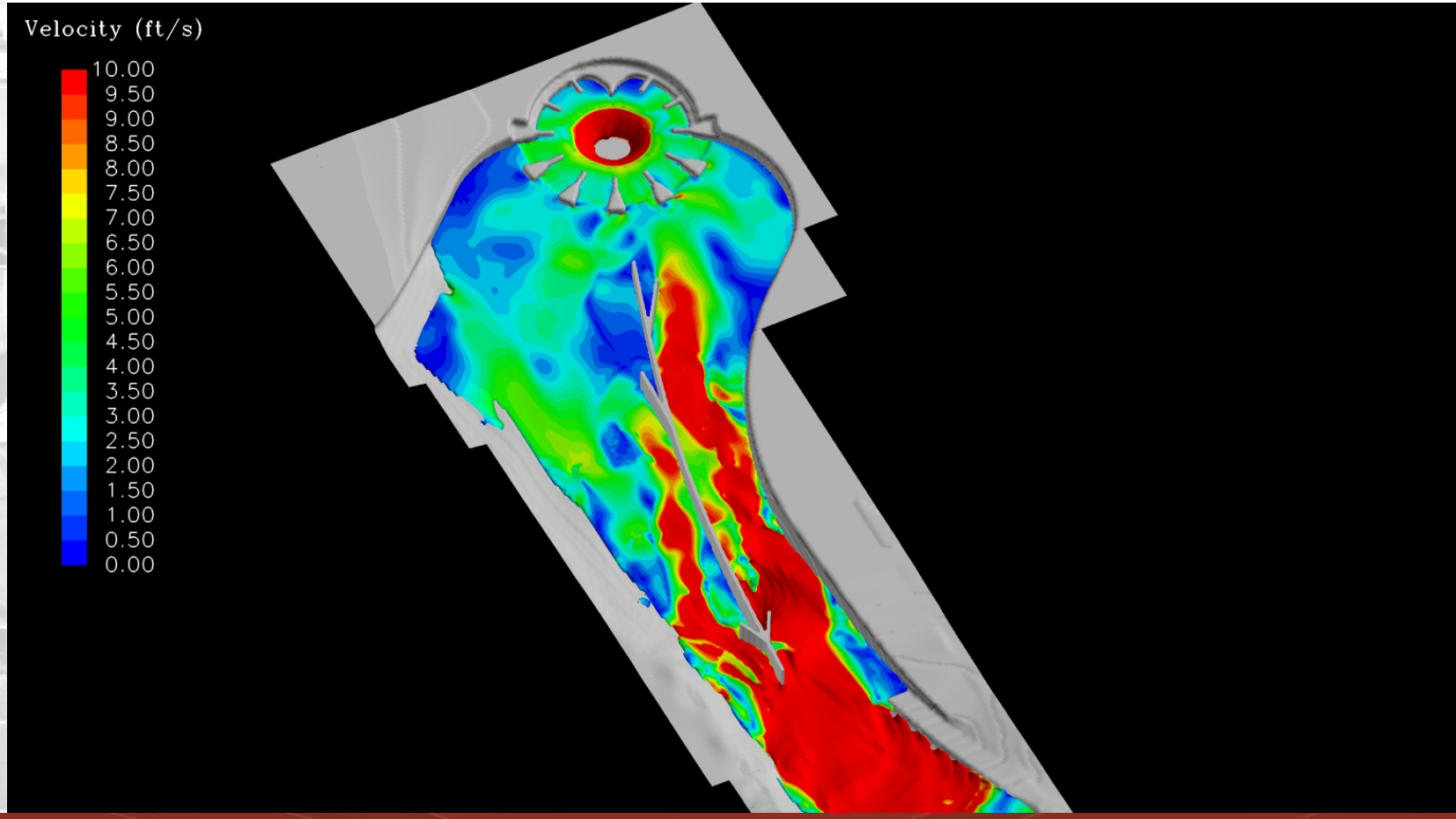


Iso-surface plot of water colored with velocity magnitude

Isometric View

Time = 2540 sec.

100 Year Flow Scenario



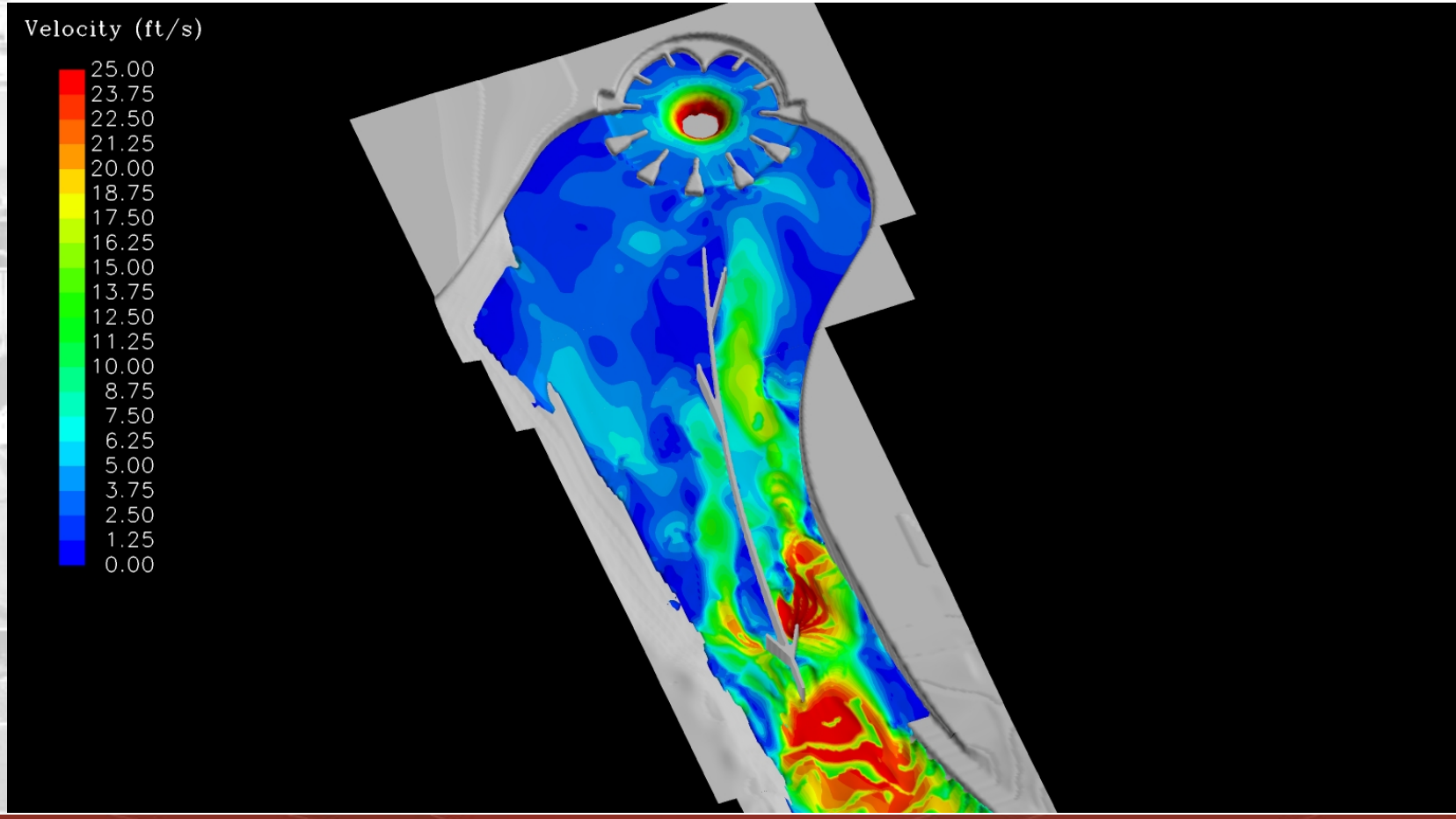
Iso-surface plot of water colored with velocity magnitude

Isometric View

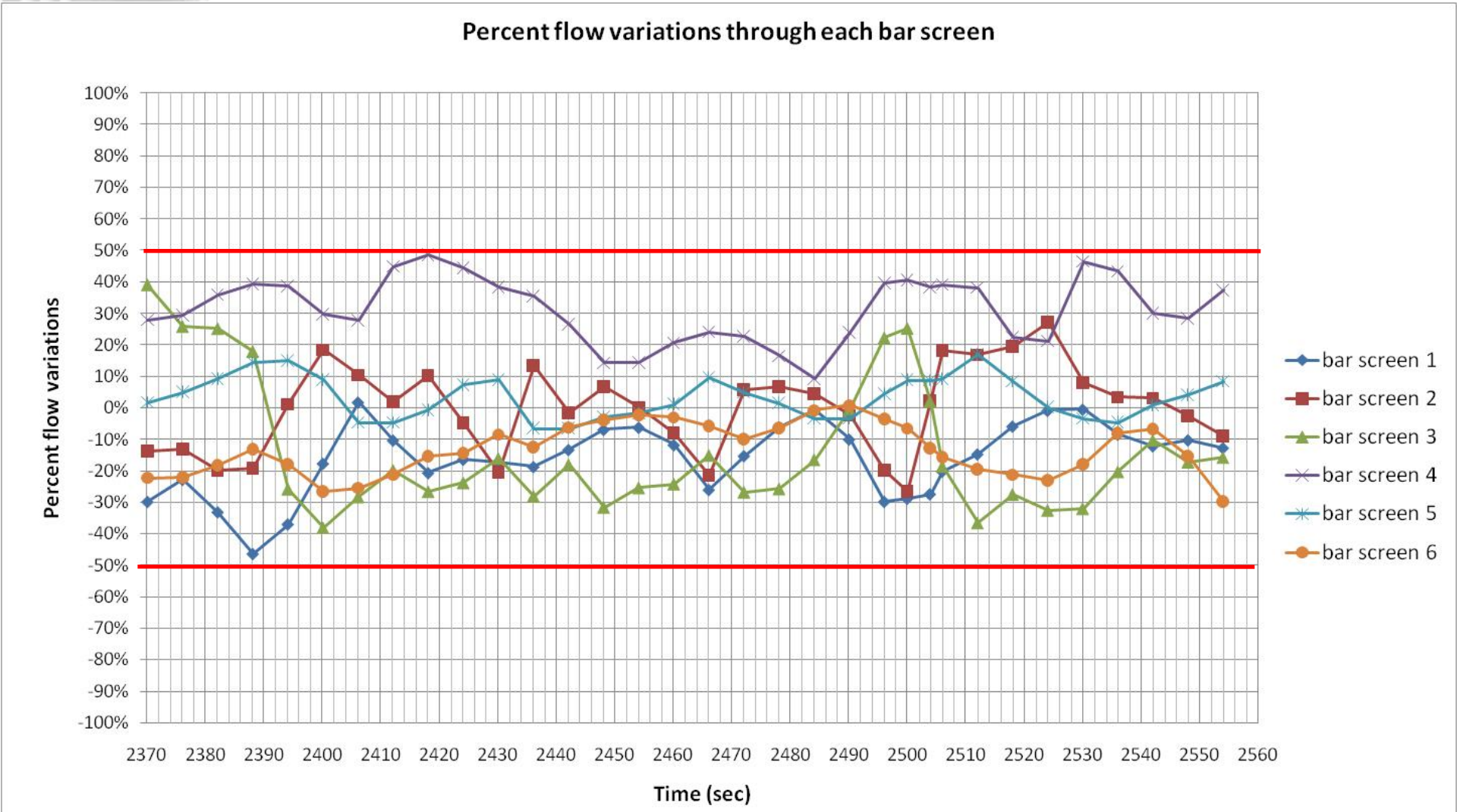
100 Year Flow Scenario

Time = 2540 sec.

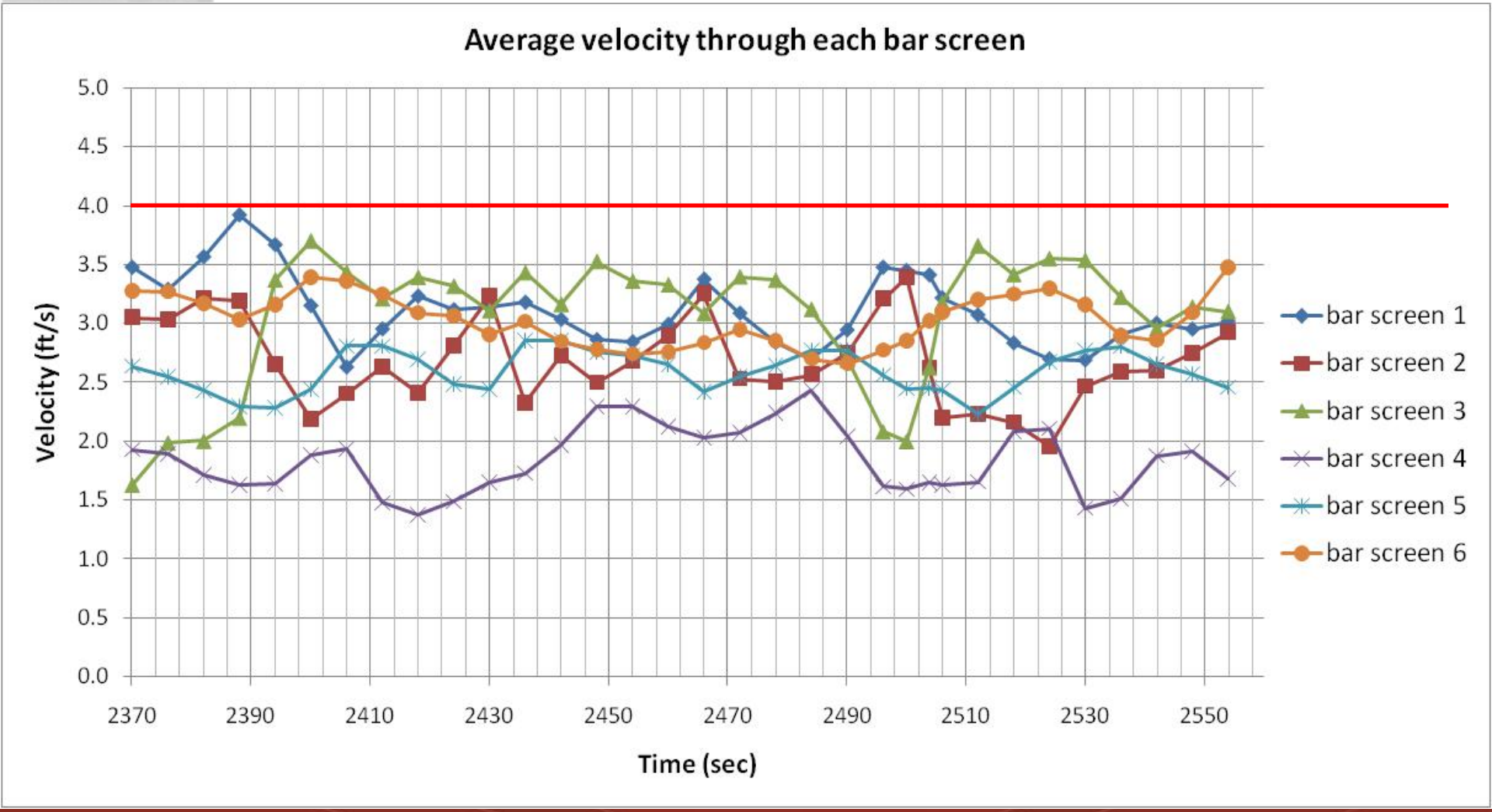
same with previous slide but different color scale



100 Year Flow Scenario



100 Year Flow Scenario

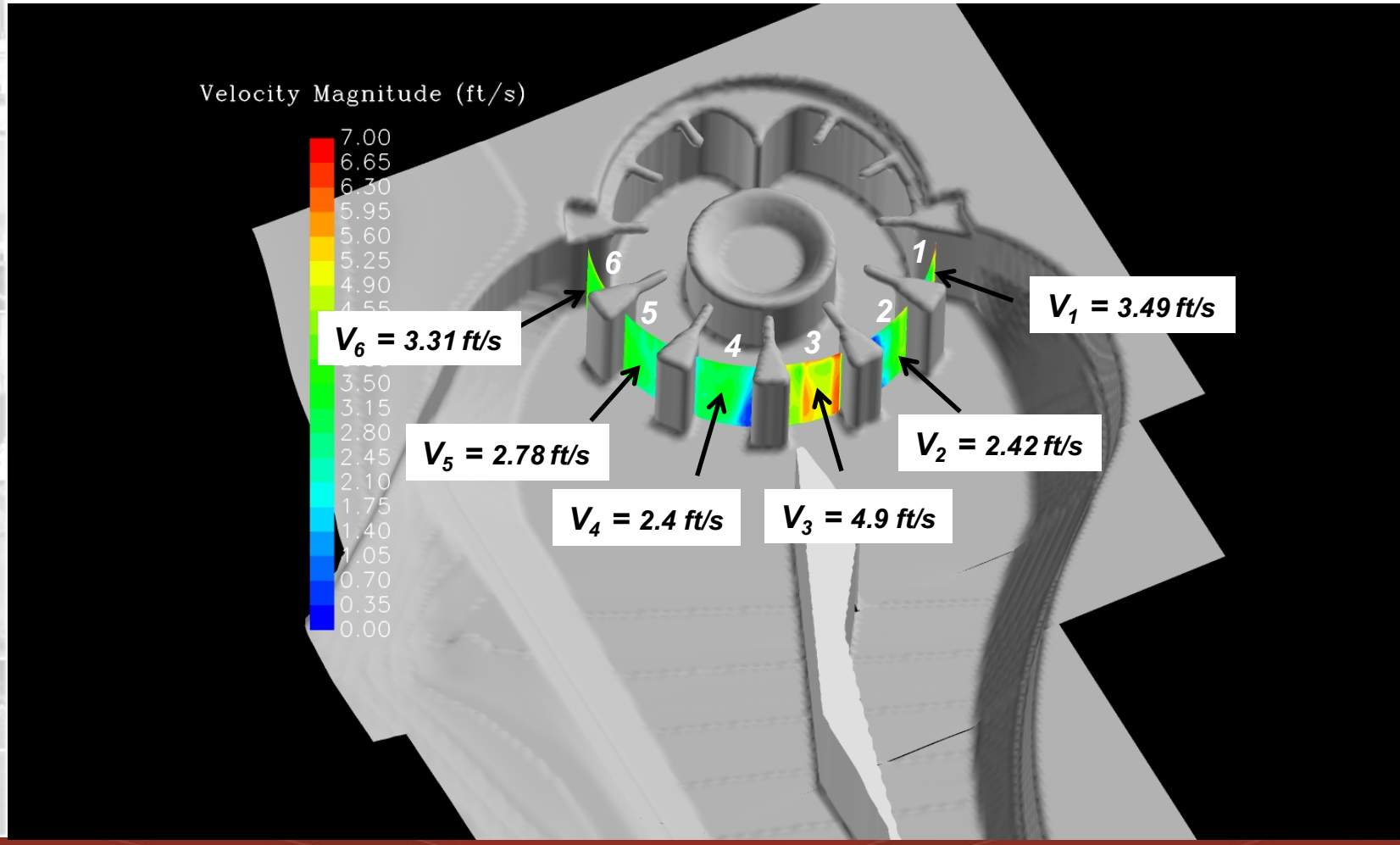


Average velocity (in the bar screen area)

(velocity color scale is the actual velocity)

Filled in Vane

100 Year Flow Scenario

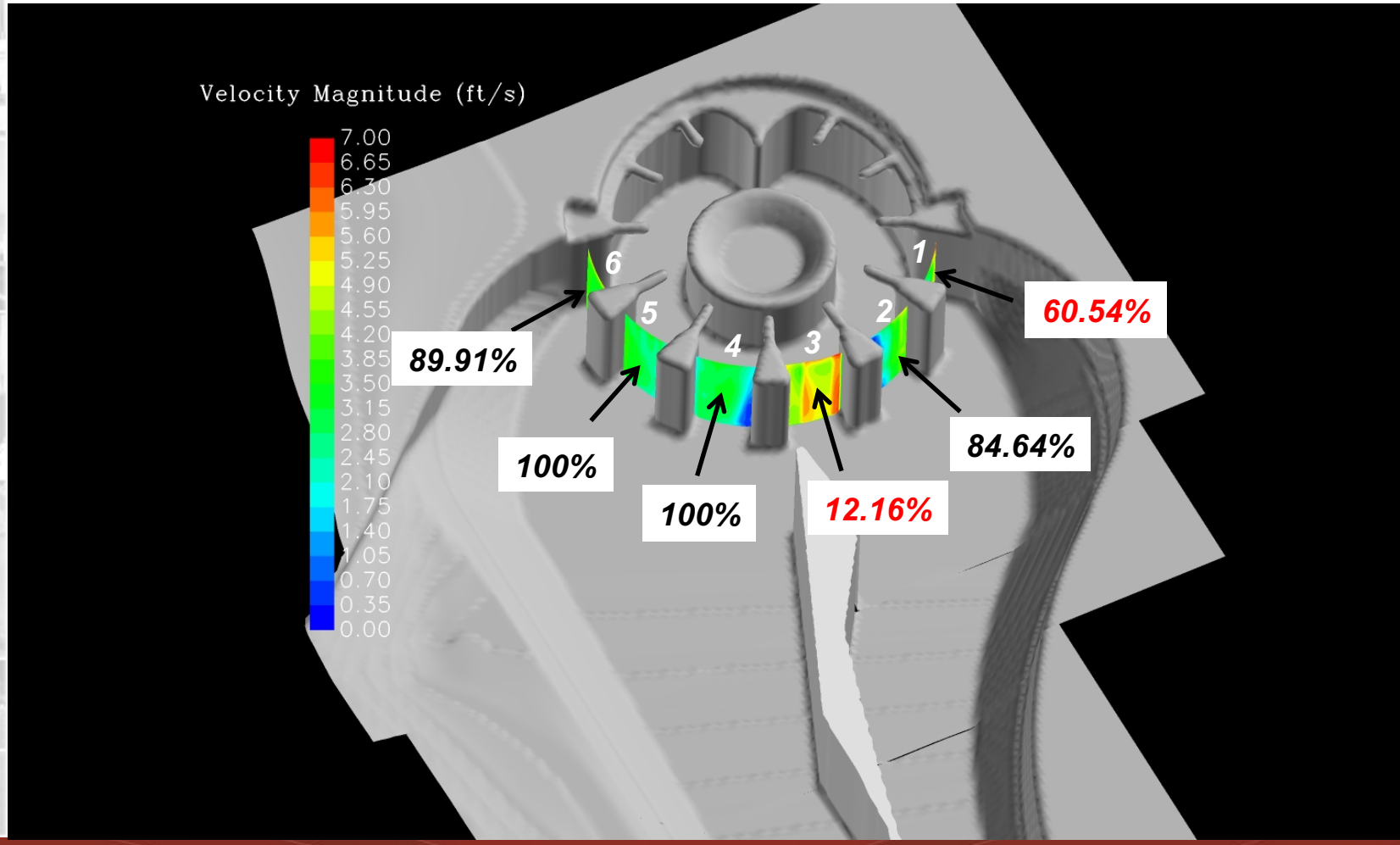


Percent of bar screen area at or below 4 ft/s

(velocity color scale is the actual velocity)

Filled in Vane

100 Year Flow Scenario

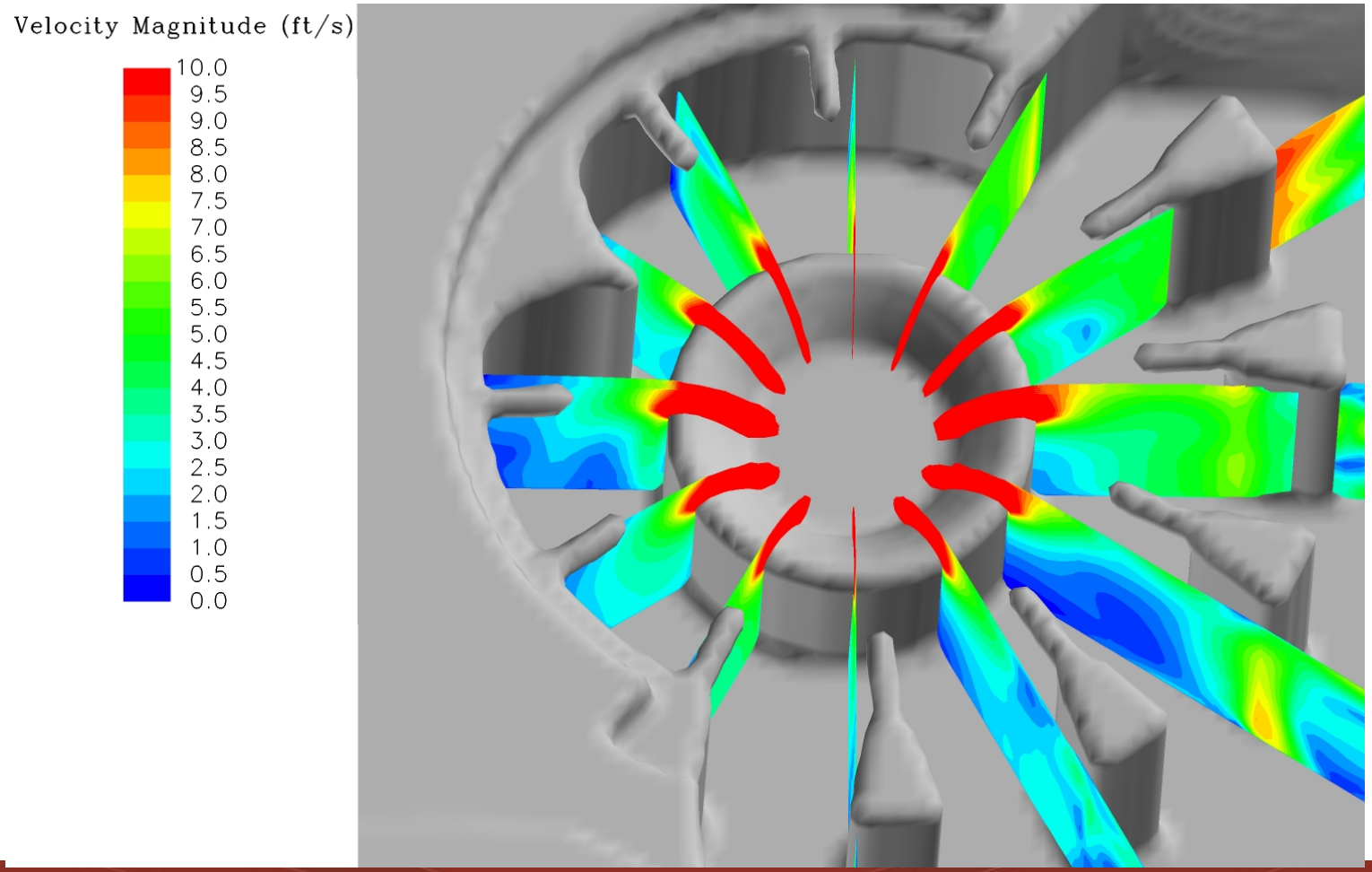


Approach Velocity to the Morning Glory Spillway

(Slice planes cut vertically at the center of the morning glory spillway at different locations.)

Isometric view 1

Filled in Vane

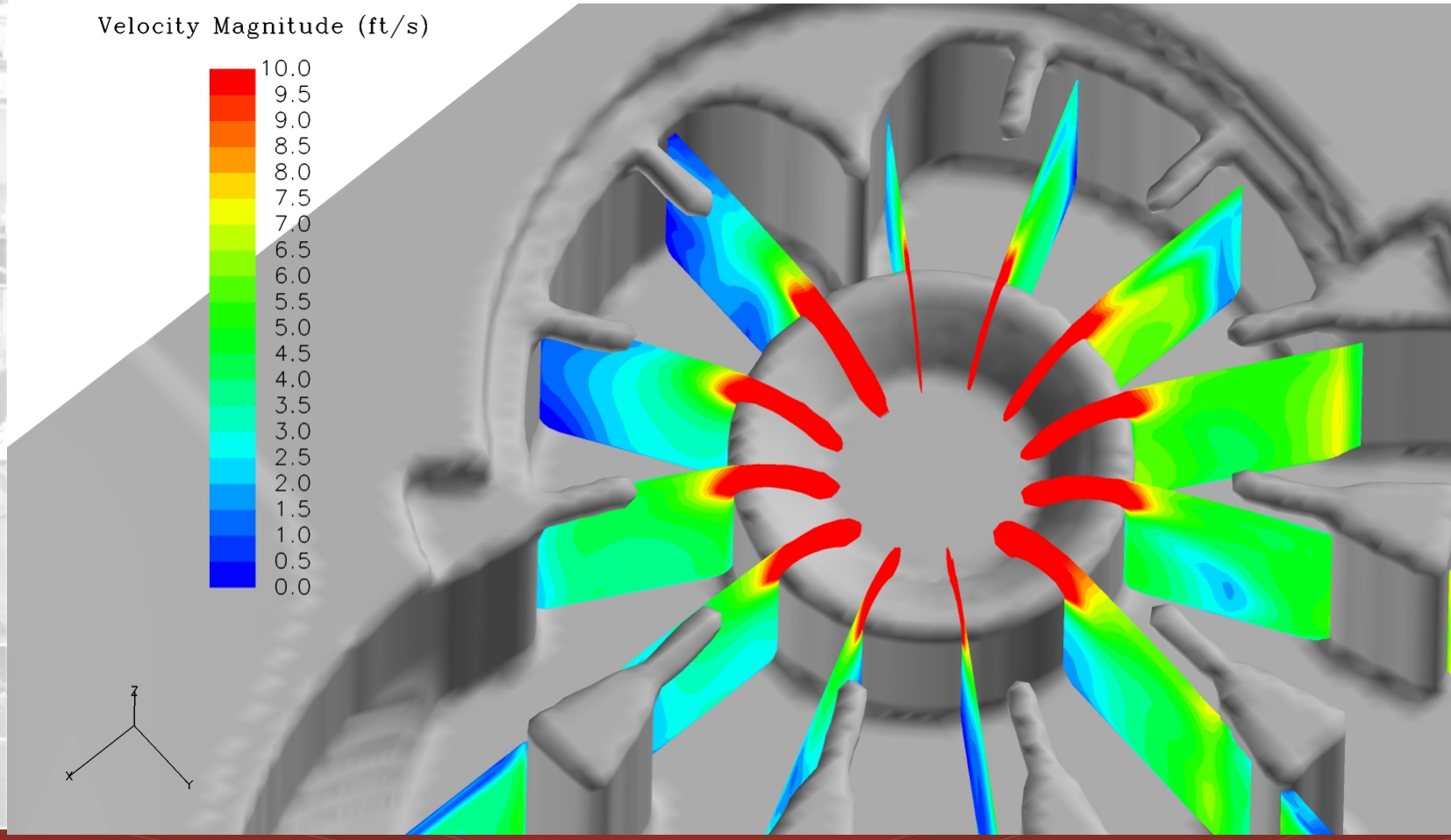


Approach Velocity to the Morning Glory Spillway

(Slice planes cut vertically at the center of the morning glory spillway at different locations.)

Isometric view 2

Filled in Vane

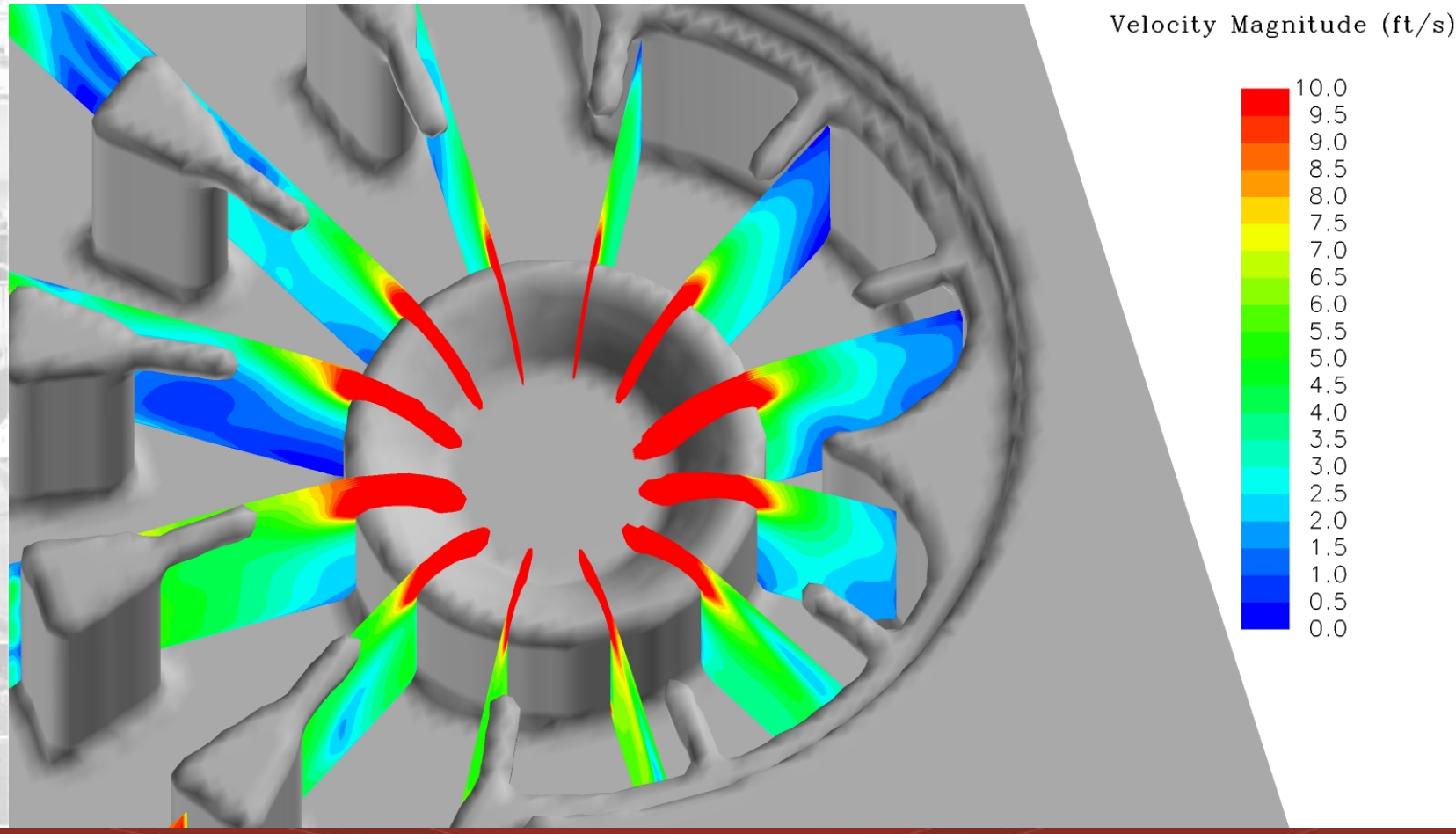


Approach Velocity to the Morning Glory Spillway

(Slice planes cut vertically at the center of the morning glory spillway at different locations.)

Isometric view 3

Filled in Vane

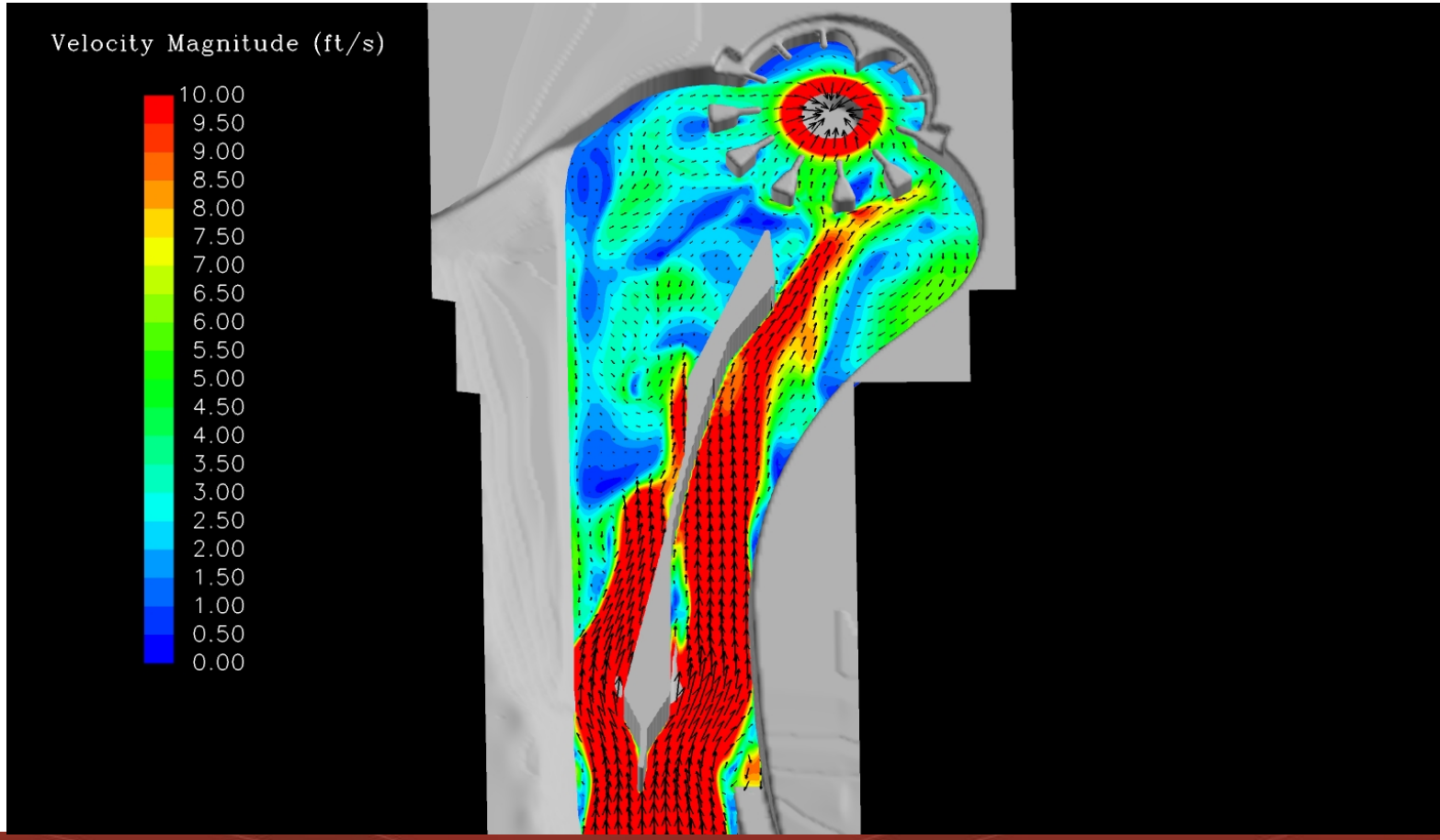


Plot of velocity contours with vectors
(slice plane cut at elevation 476 ft.)

Isometric View

Filled in Vane

100 Year Flow Scenario

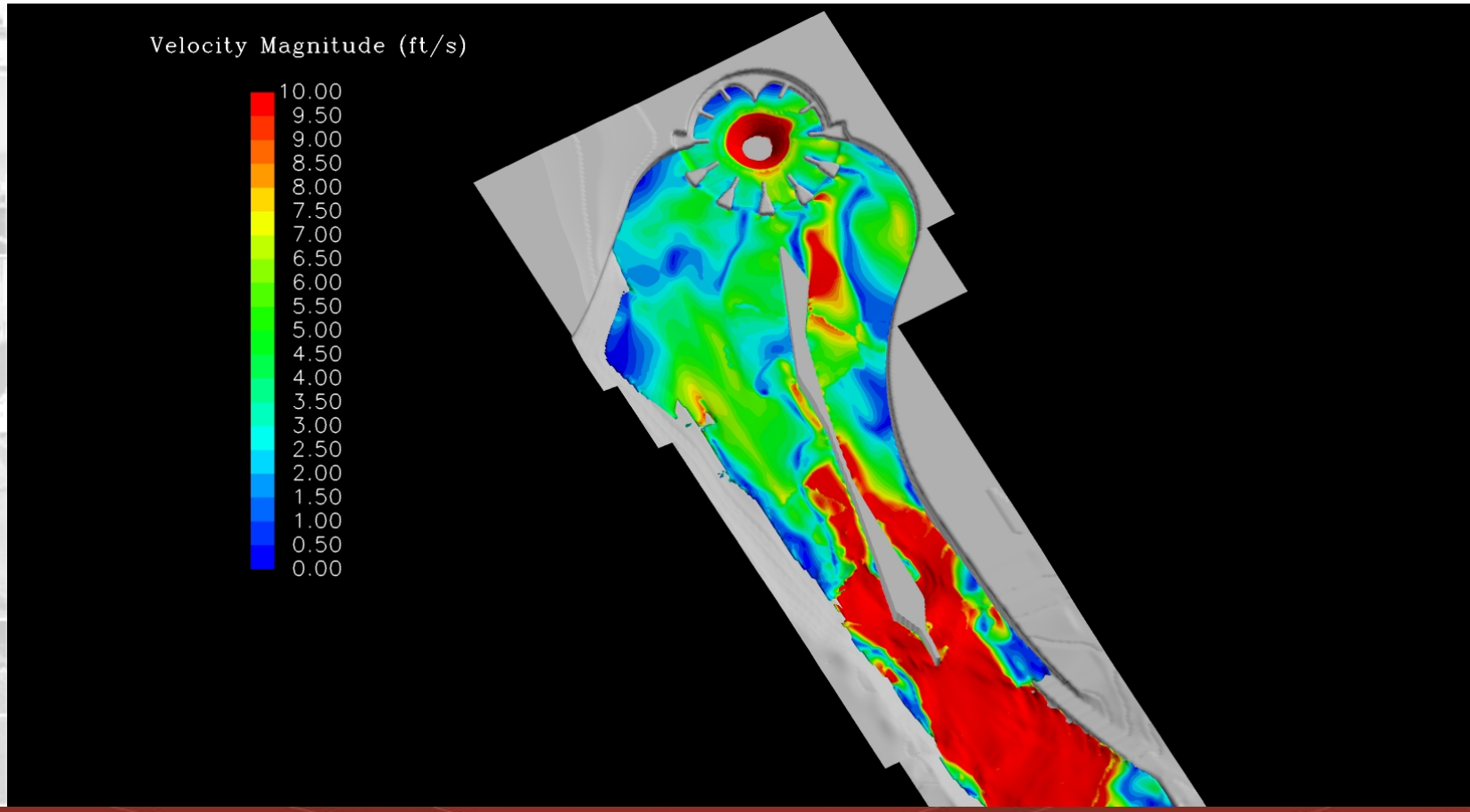


Iso-surface plot of water colored with velocity magnitude

Isometric View

Filled in Vane

100 Year Flow Scenario



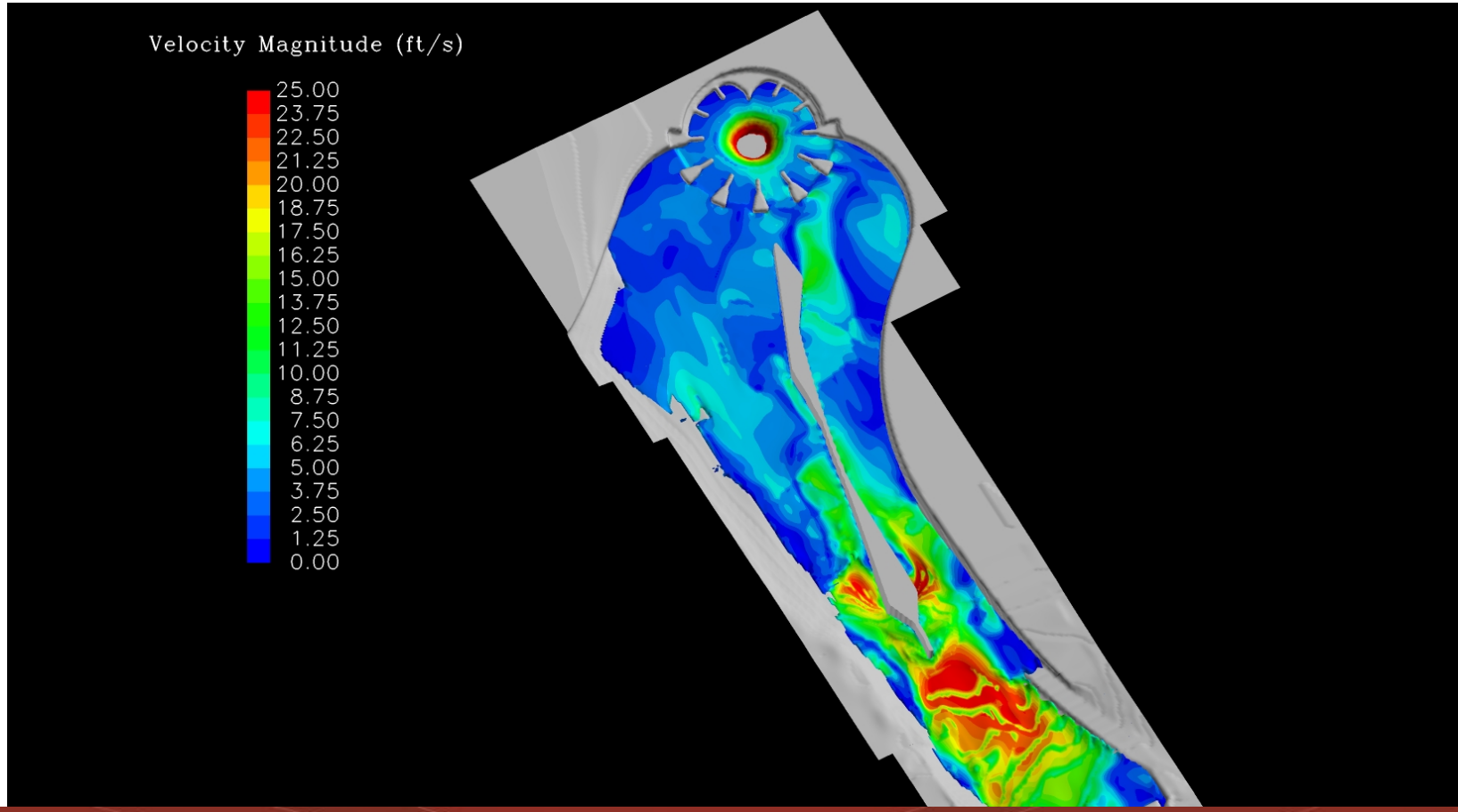
Iso-surface plot of water colored with velocity magnitude

Isometric View

100 Year Flow Scenario

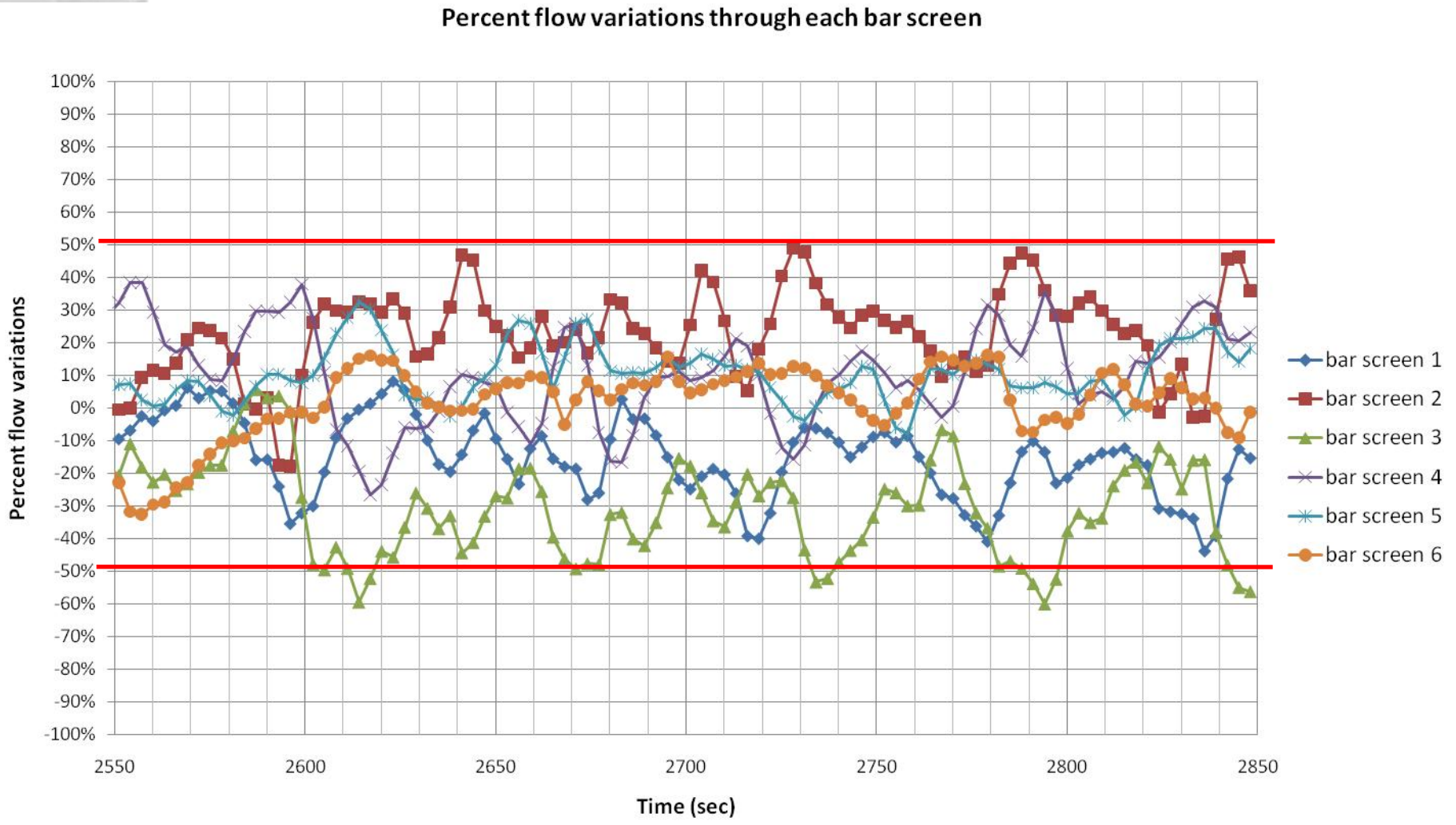
Filled in Vane

same with previous slide but different color scale



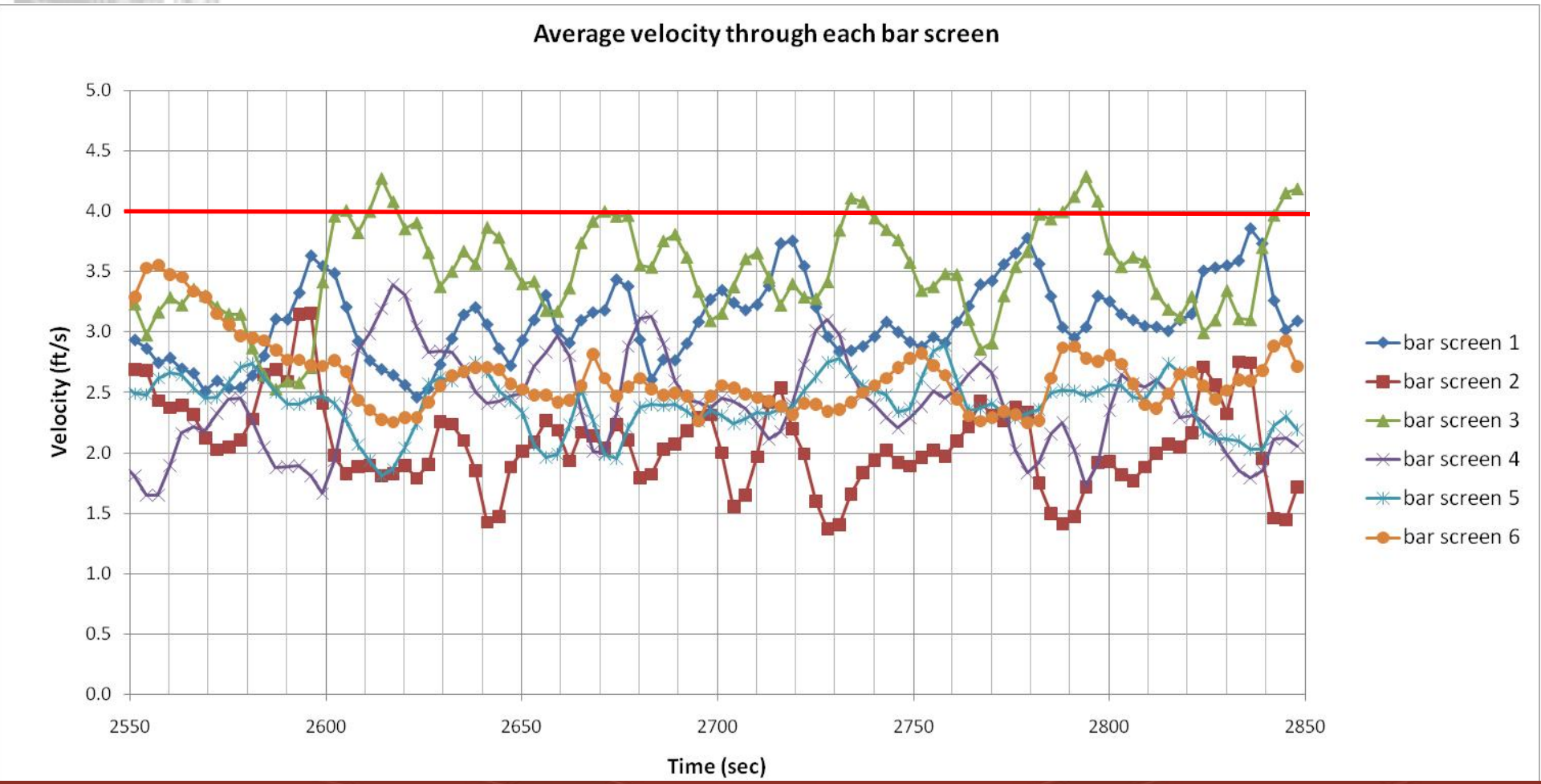
100 Year Flow Scenario

Filled in Vane



100 Year Flow Scenario

Filled in Vane



CFD Models Tunnel-Lateral Junctions

Objectives:

1. Conduct detailed assessment of proposed designs:
   - Flow Patterns
   - Flow Velocities
   - Areas of Flow Separation
   - Potential for Cavitation
2. Design modifications to improve any adverse hydraulic conditions.
3. Selection of a final design for further evaluation in the physical model

CFD Models Tunnel-Lateral Junctions

Acceptance Criteria:

1. Minimize flow separations at the lateral junctions.
2. Avoid the occurrence of cavitation.

Modifications to Date: None Required Based on Results

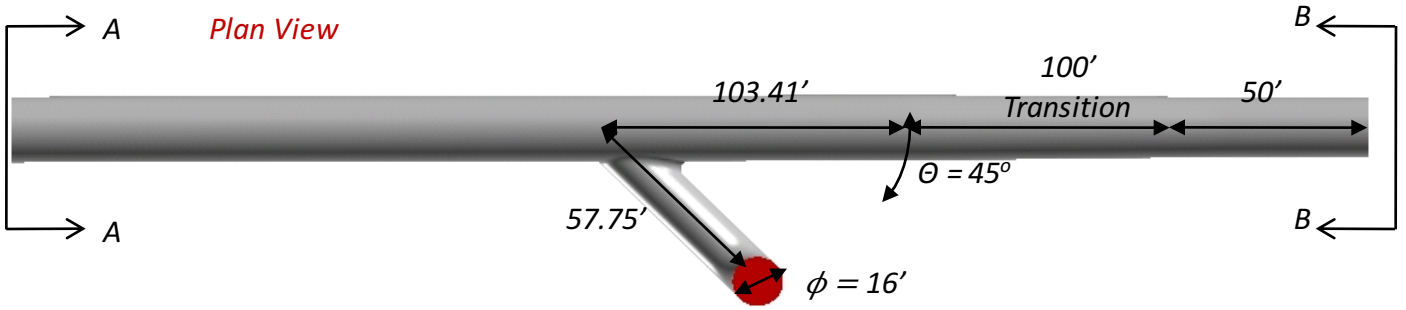
CFD Models Tunnel-Lateral Junctions

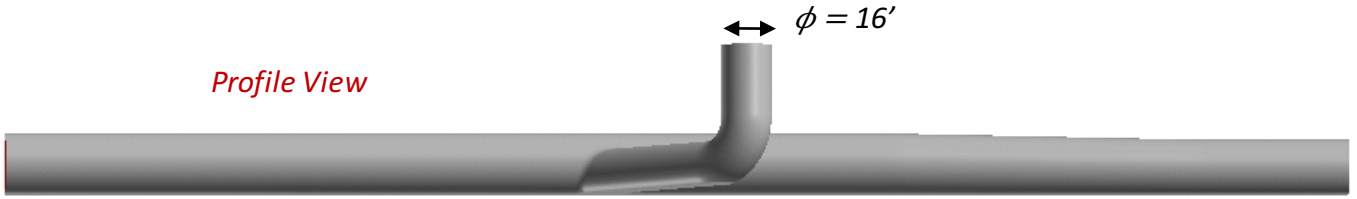
Flow Conditions Tested

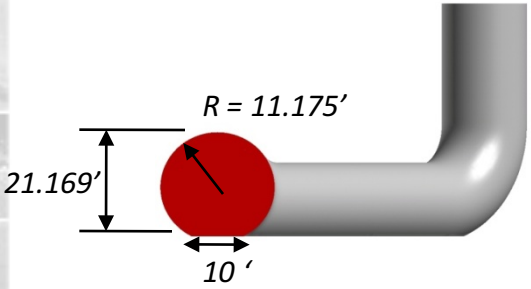
	Return Period	1 yr	2 yr	5 yr	10 yr	100 yr	500 yr
Proposed - Lag Tunnel / Peak Intervening Flow (8th Street Lateral Junction)	Tunnel Flow (12th St. Inlet)	632	979	1972	2743	4693	6208
	8th St. Connector Tunnel Flow	260	335	547	700	1258	1701
	% Flow of 8th St. Connector Tunnel	41.1%	34.2%	27.7%	25.5%	26.8%	27.4%
Proposed - Lag Tunnel / Peak Intervening Flow (4th Street Lateral Junction)	Tunnel Flow (12th St. Inlet + 8th St. Inlet)	892	1314	2519	3443	5951	7909
	4th St. Connector Tunnel Flow	194	239	361	447	763	1015
	% Flow of 4th St. Connector Tunnel	21.7%	18.2%	14.3%	13.0%	12.8%	12.8%

Note: Only 1 yr and 100 yr return period were tested.
Units of flow rates in cfs.

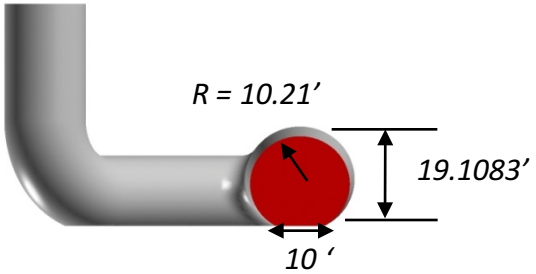
8th St. Lateral Junction: Model Geometry





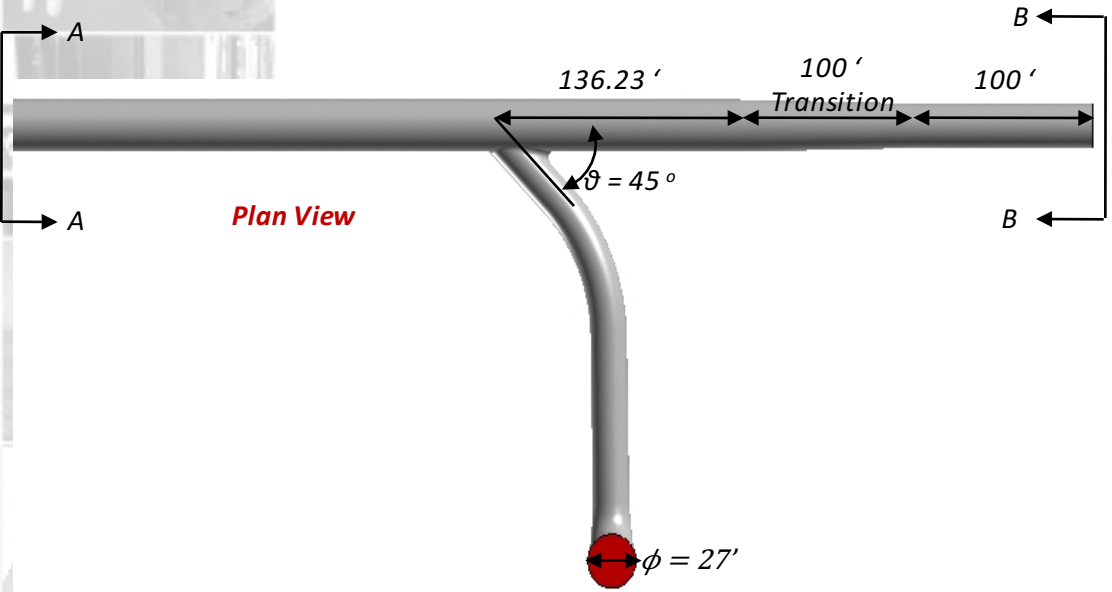


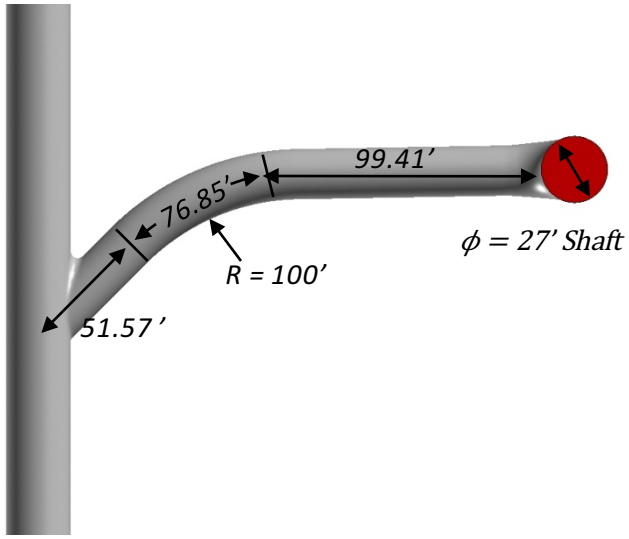
Section A-A

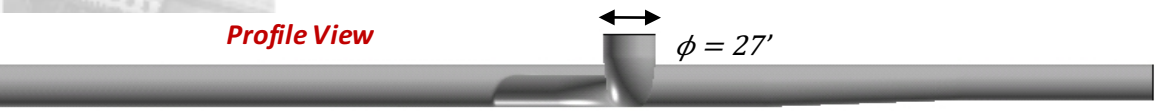


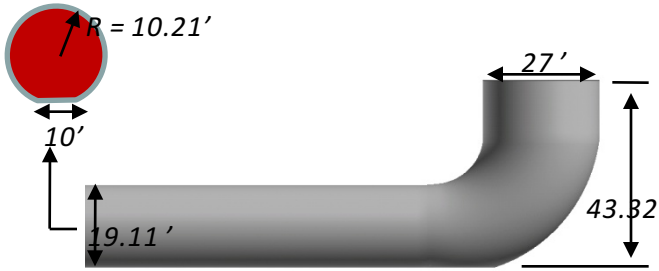
Section B-B

4th St. Lateral Junction: Model Geometry



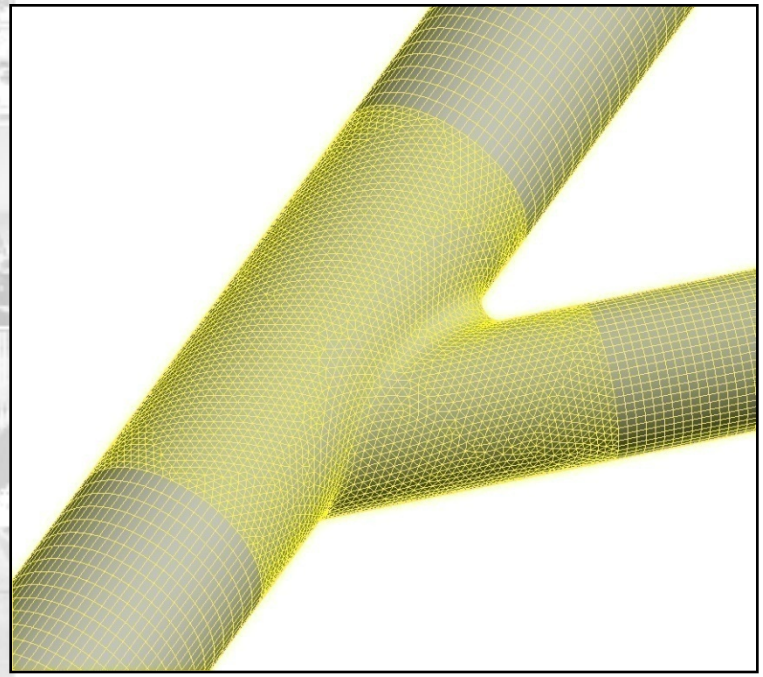


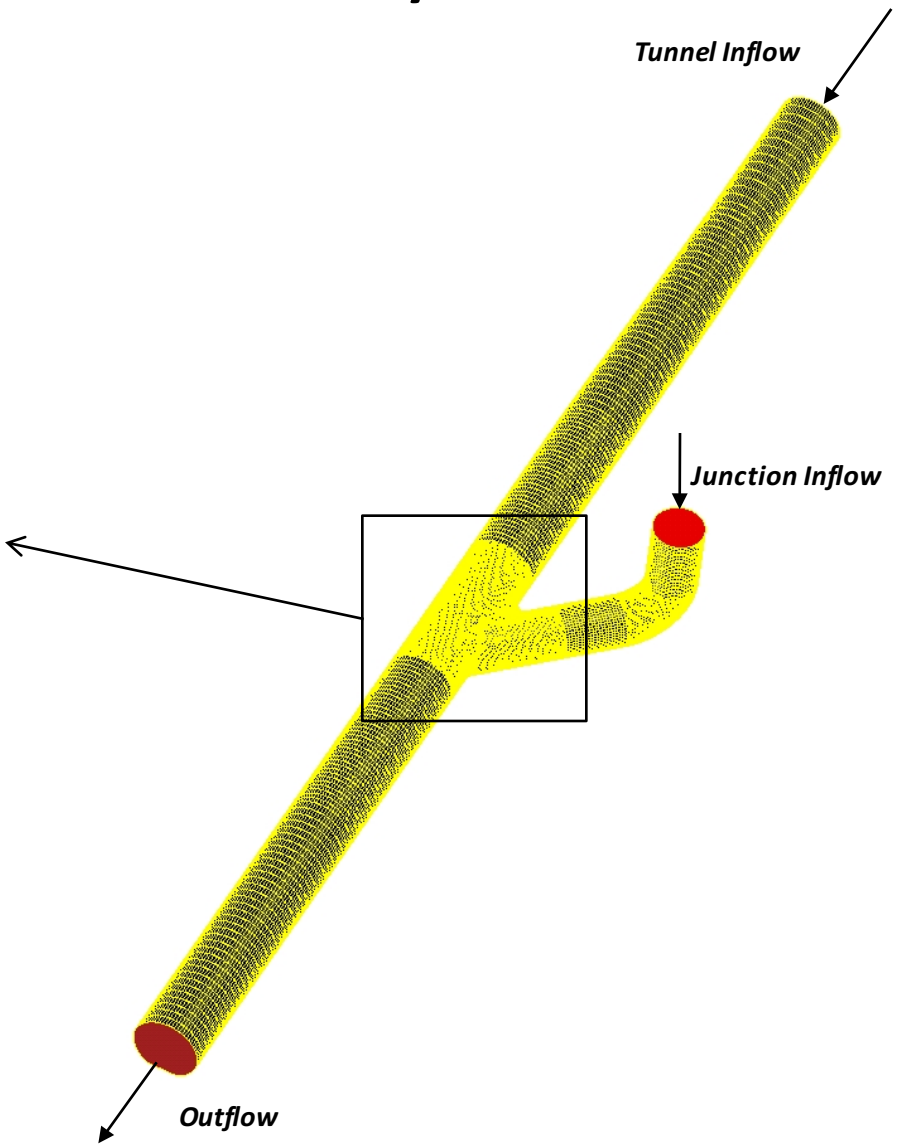




8th St. Lateral Junction: Mesh and Boundary Conditions

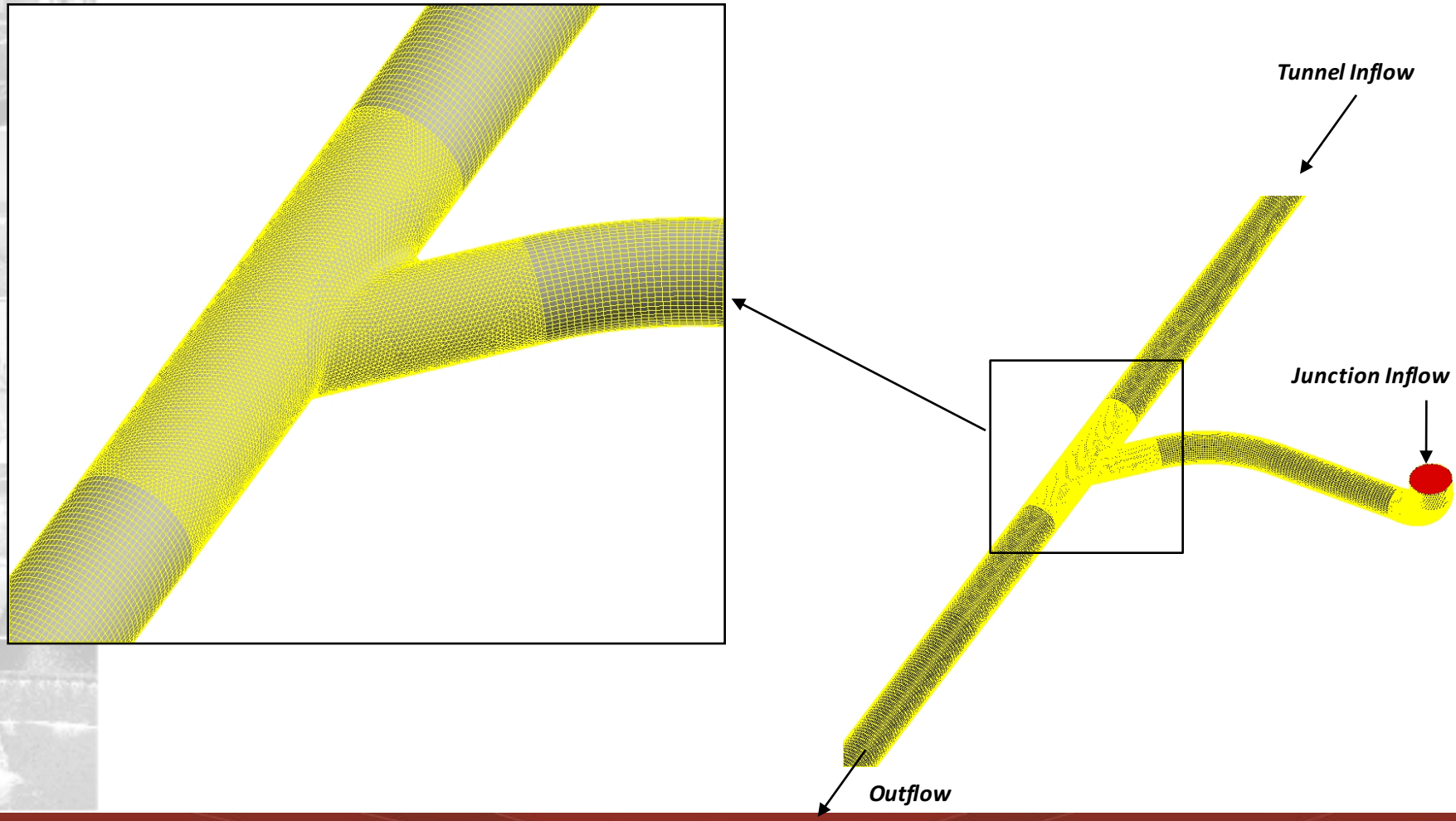
No. of Cells: *~ 310,000 cells*





4th St. Lateral Junction: Mesh and Boundary Conditions

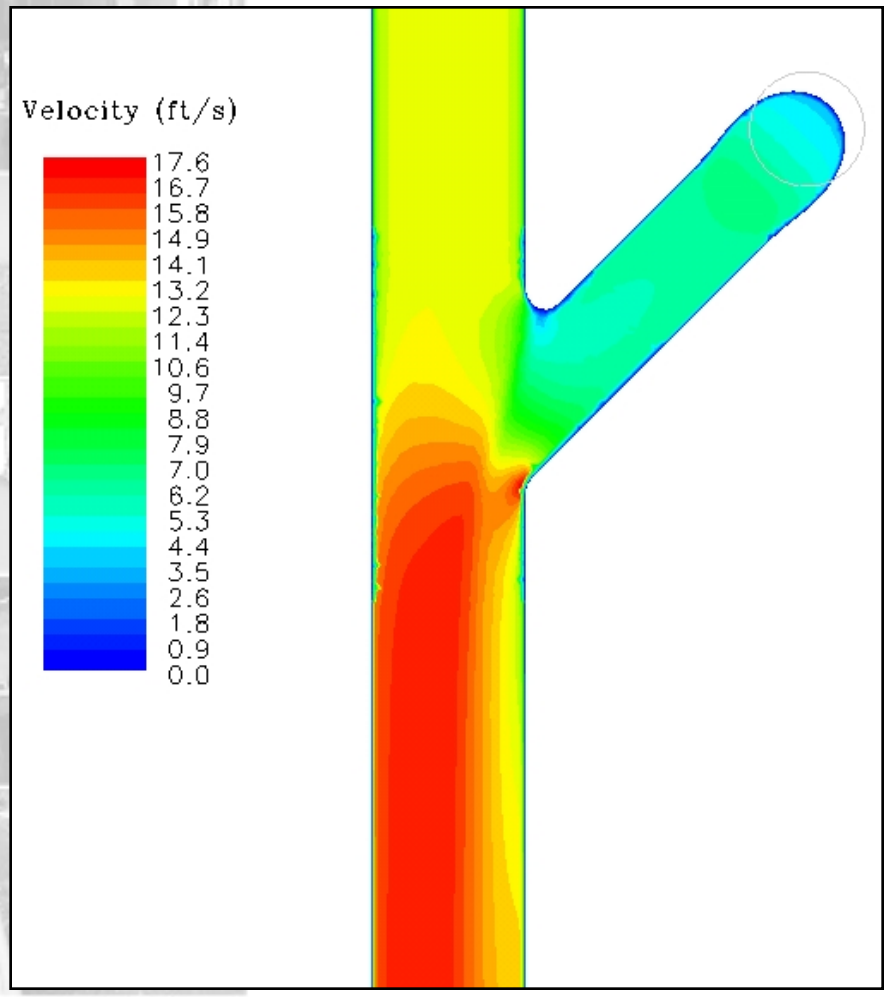
No. of Cells: *~ 500,000 cells*

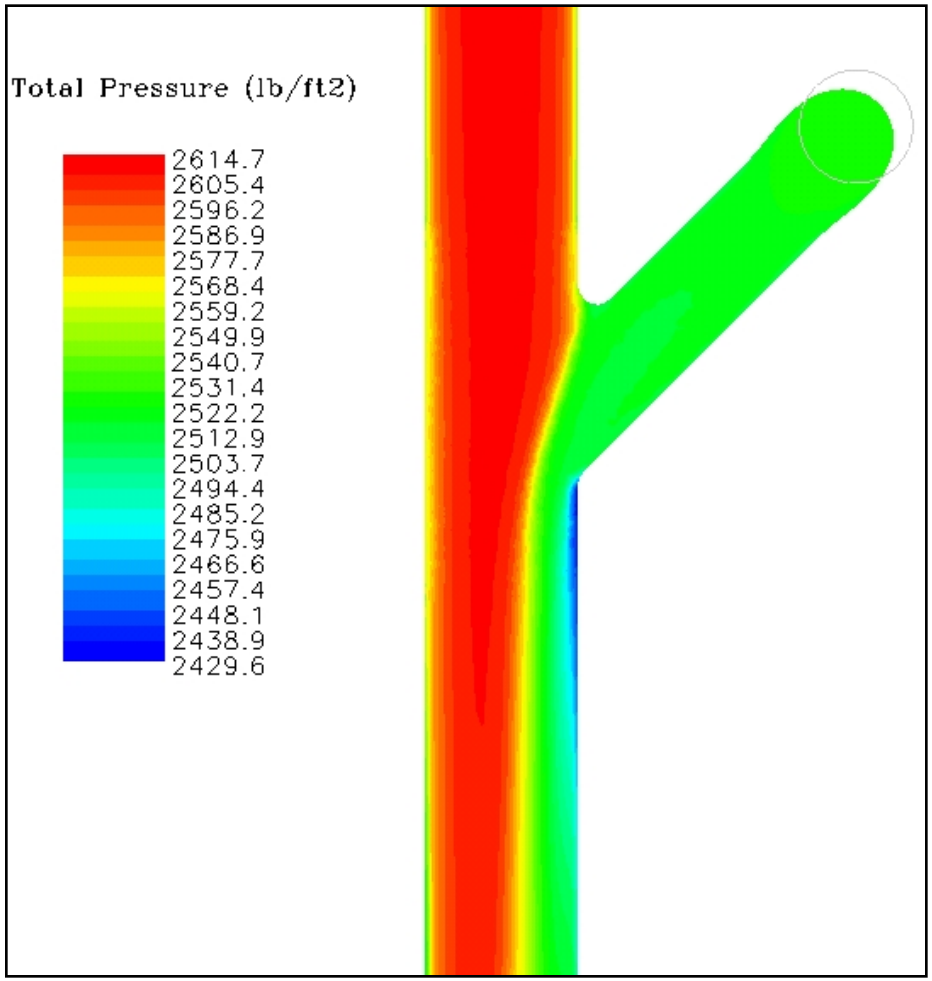


CFD Models Tunnel-Lateral Junctions
Model Summary

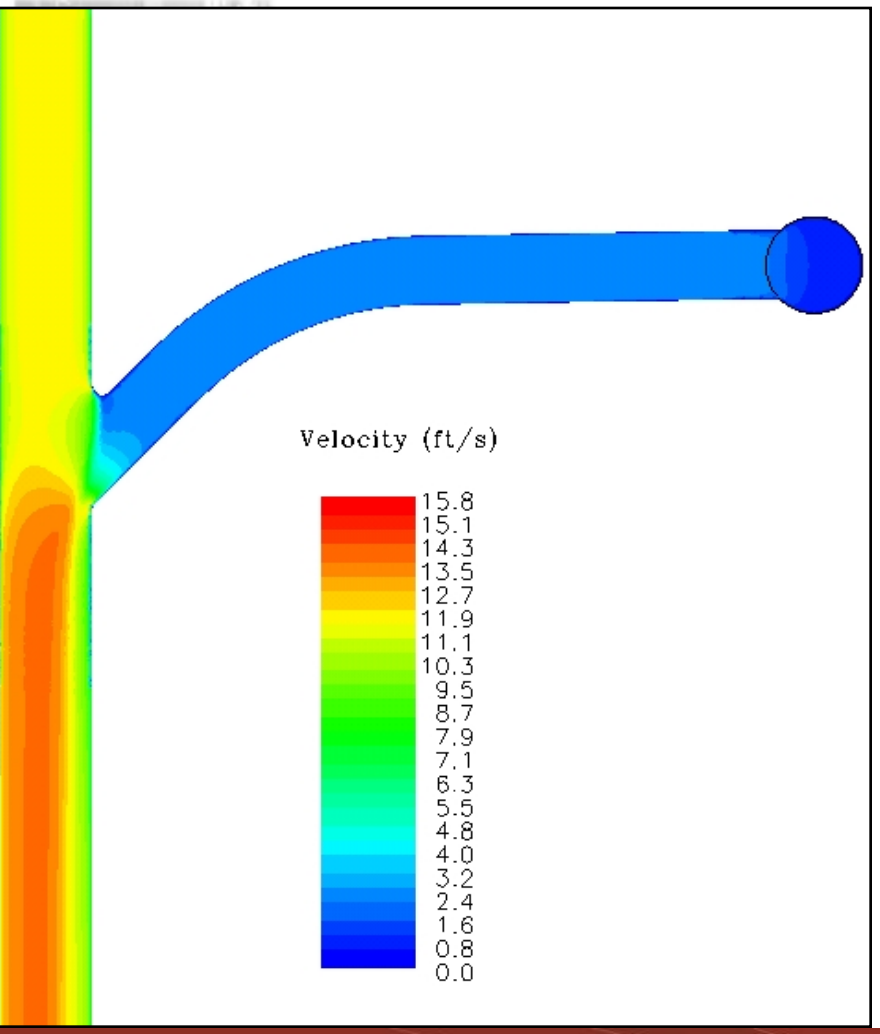
- **Developed in Fluent (Version 6.3) by ANSYS**
- **Hybrid grid with a total of about 500,000 cells.**
- **Water solid / One fluid.**
- **Physics**
  - Steady-state flow (time-average)
  - Gravity
  - K- epsilon turbulence model with no-slip wall boundary condition
- **Boundary conditions:**
  - Inflow
    - Tunnel inflow: specified velocity.
    - Connector tunnel inflow: specified velocity.
  - Outflow
    - Tunnel outflow: outflow boundary with zero gradient of flow.

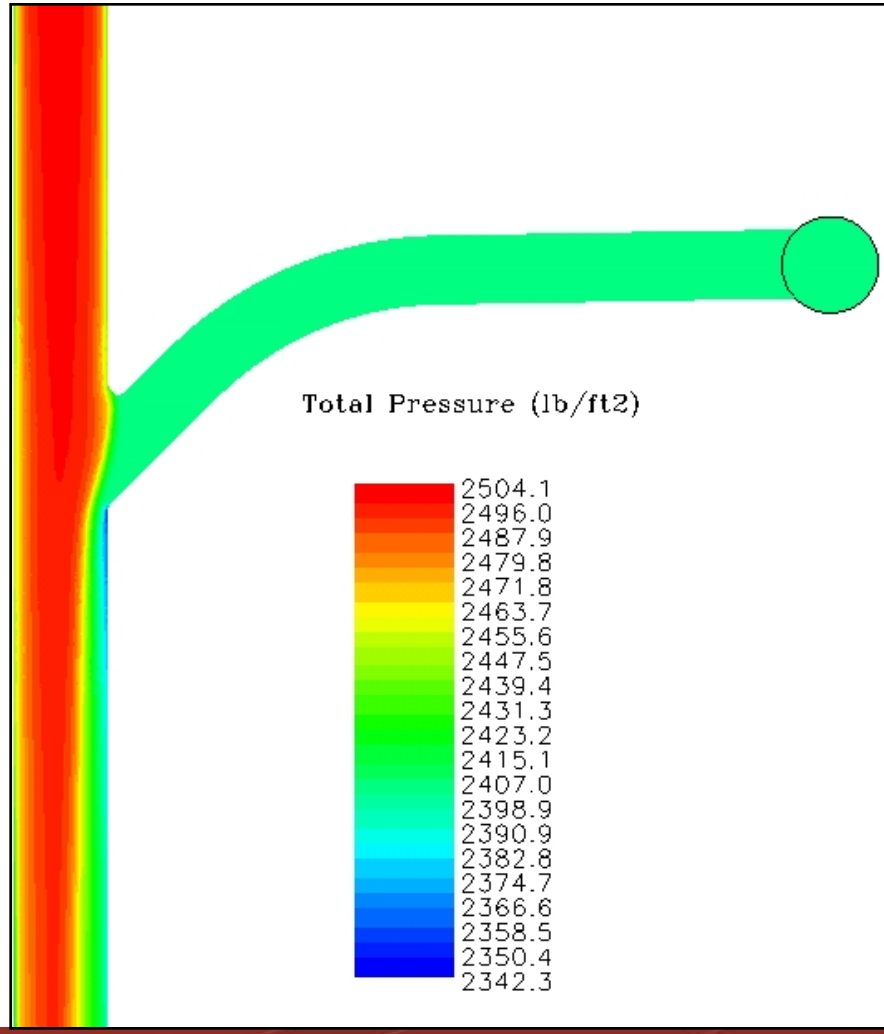
8th St. Lateral Junction: 100 Year Return Period

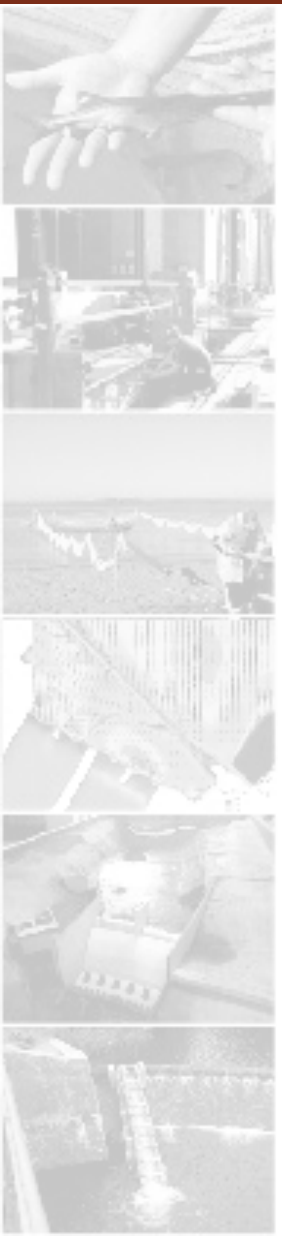




4th St. Lateral Junction: 100 Year Return Period







CFD Models Outlet Structure

Objectives:

1. Detailed assessment of proposed designs:

- Flow patterns between tunnel shaft and spillway
- Flow impact caused by blocks at ends of the spillway crest.
- Velocity profiles along the ogee spillway section
- Hydraulic jump at the toe of the spillway
- Scour potential in exit channel, concrete apron and riprap section
- Water surface elevations at spillway crest and upstream
- Pressure force on the pipe riser and water intake screen

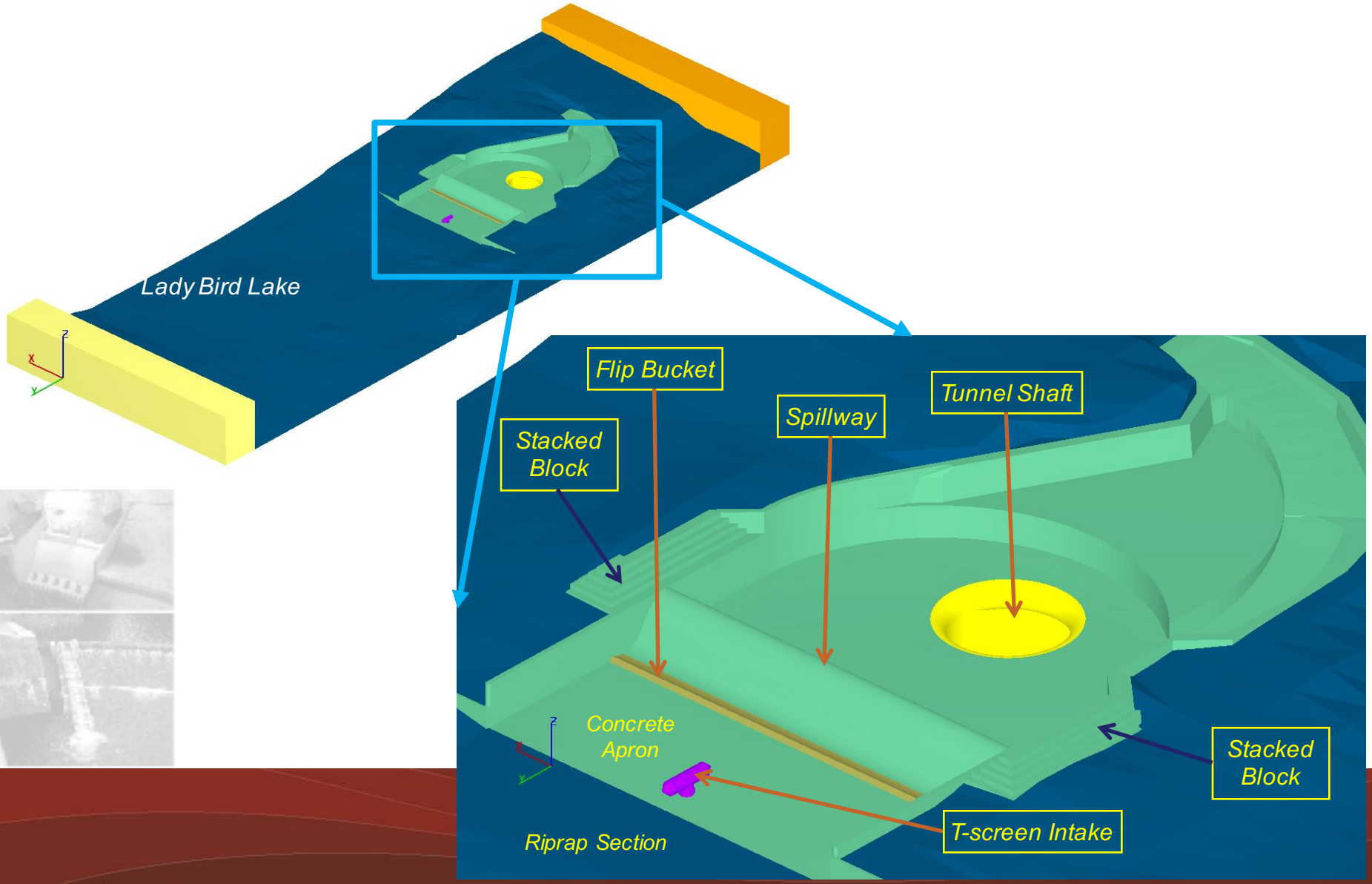
CFD Models Outlet Structure

Objectives (continued):

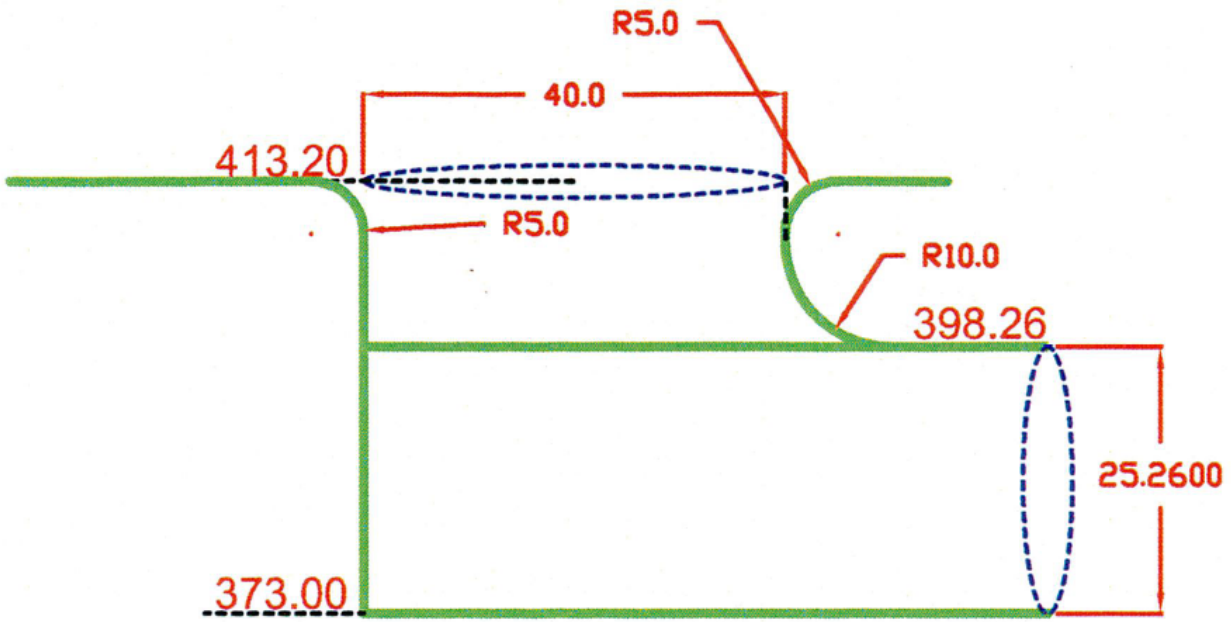
2. Design modifications to improve any adverse hydraulic conditions.
3. Selection of a final design for further evaluation in the physical model

Run	Description			
	Outlet Connection	Flowrate	Lady Bird Lake Cross Flow	Spillway Flip Bucket
1	#1	100-yr flood, 7957 cfs	no cross flow	n/a
2	#1	100-yr flood, 7957 cfs	3.5 ft/s cross flow, El. 428 ft	n/a
3	#2	100-yr flood, 7957 cfs	3.5 ft/s cross flow, El. 428 ft	3 ft high
4	#2	500-yr flood, 11270 cfs	3.5 ft/s cross flow, El. 428 ft	3 ft high
5	#2	2-yr flood, 2320 cfs	1.25 ft/s cross flow, El. 428 ft	3 ft high
6	#2	100-yr flood, 7957 cfs	3.5 ft/s cross flow, El. 428 ft	1.5 ft high
7	#2	100-yr flood, 7957 cfs	3.5 ft/s cross flow, El. 428 ft	2.25 ft high

CFD Models Outlet Structure

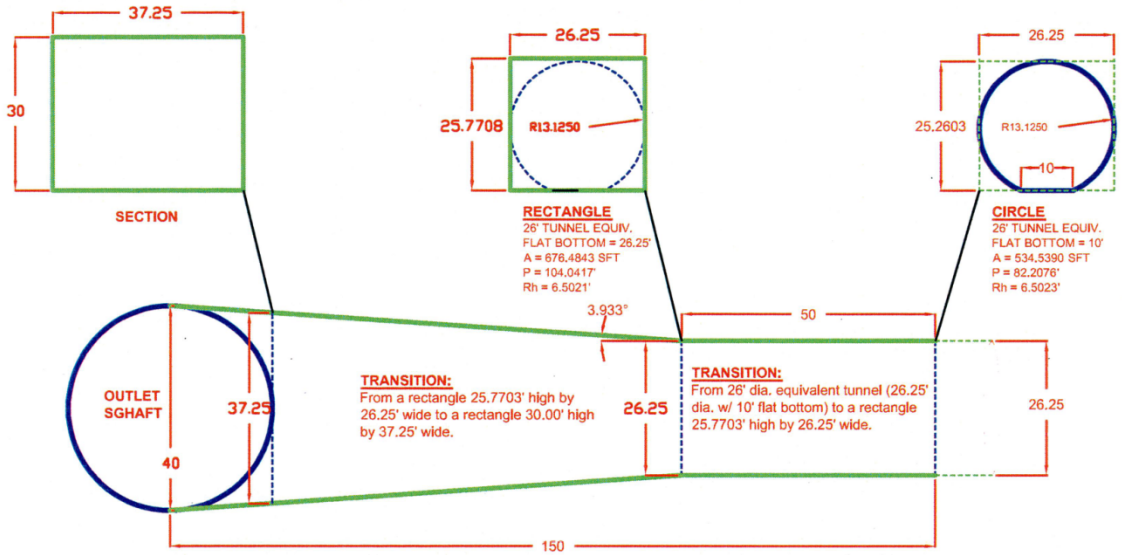


Connection Alternatives

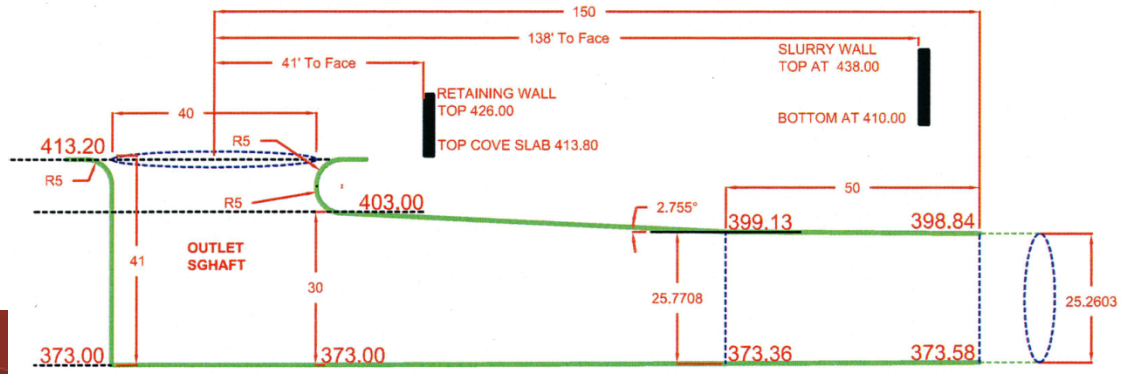


OUTLET CONNECTION #1

Connection Alternatives



OUTLET CONNECTION #2
PLAN

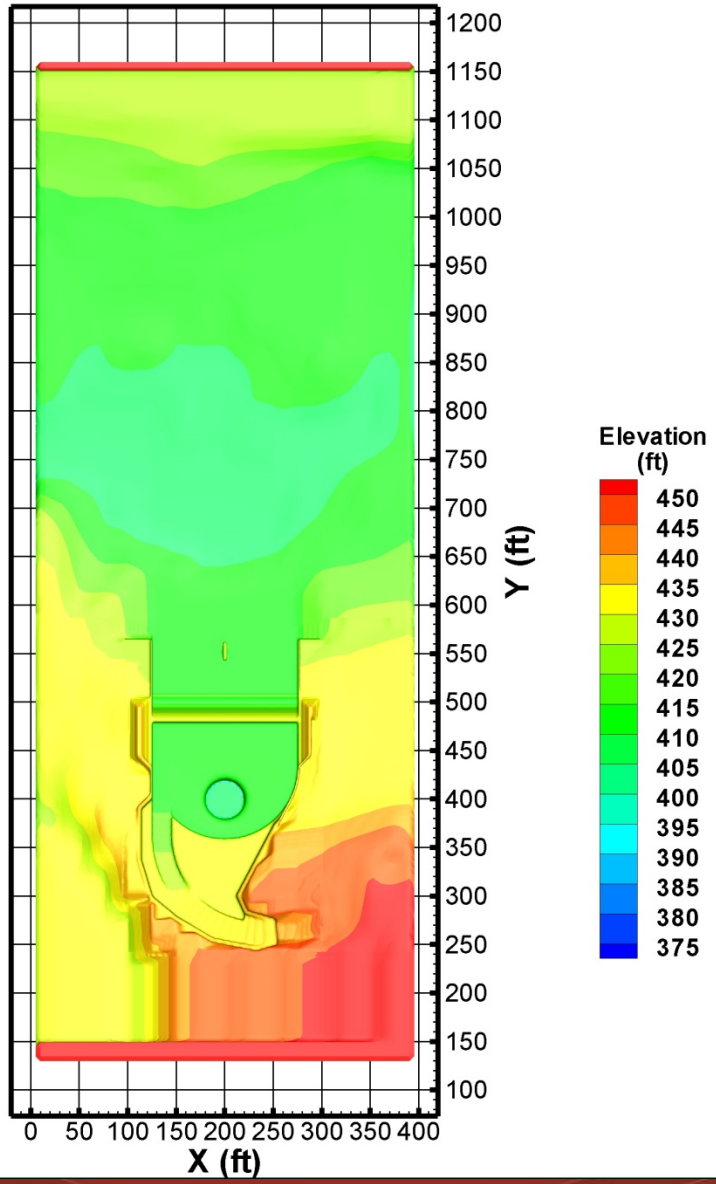


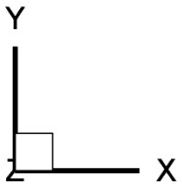
OUTLET CONNECTION #2
PROFILE

Plan View of Waller Creek Outlet CFD Model
Connection #2

Center of Outlet Shaft @
(X, Y)=(200', 400')

Tunnel Shaft Bottom @ El. 373'
Outlet Cove Slab @ El. 414'
Spillway Crest @ El. 430'

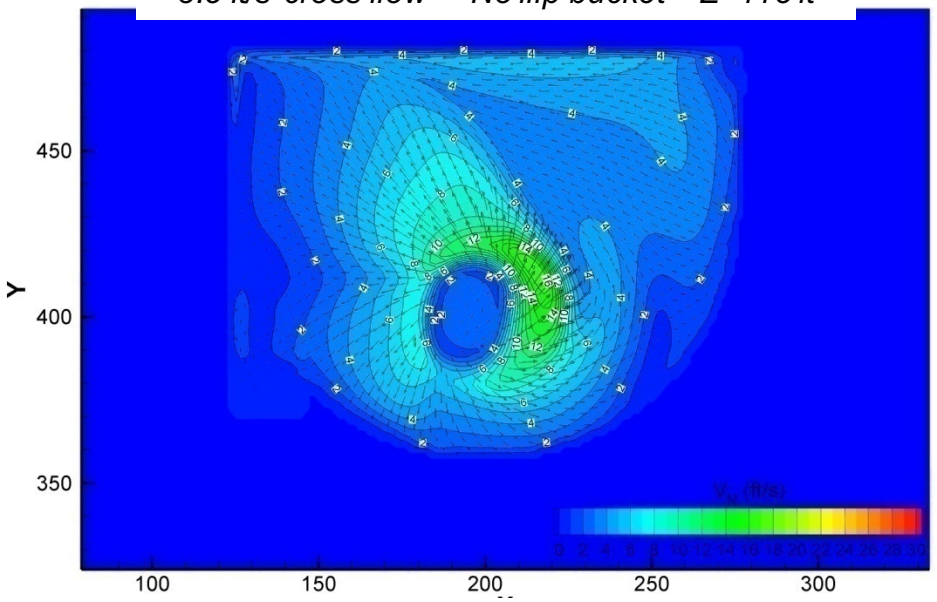




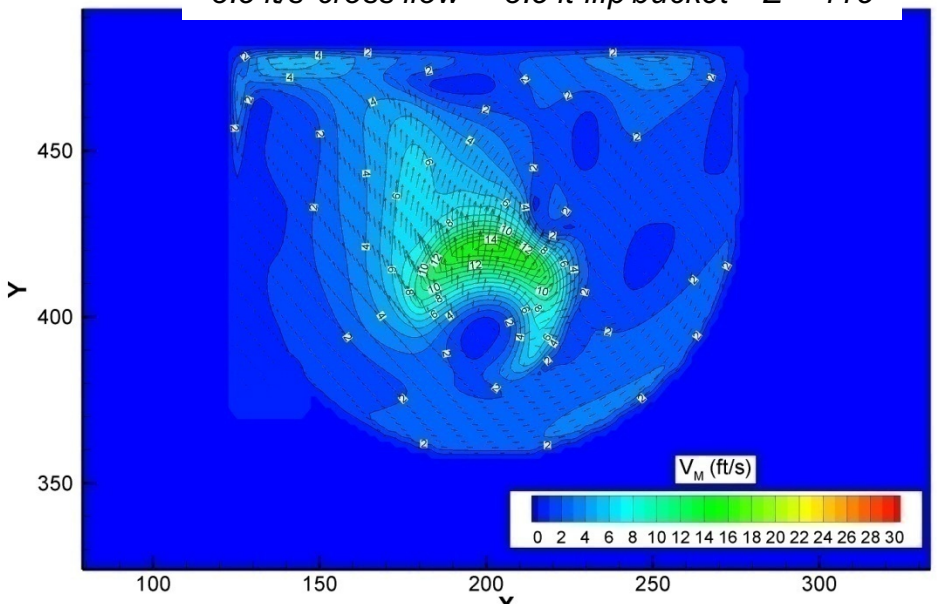
CFD Models Outlet Structure Summary

- Flow 3D (Version 9.3) of Flow Science, Inc.
- Multiple mesh blocks with a total of about 2,500,000 cells.
- One fluid with free surface.
- Physics
  - Unsteady flow (time-dependent)
  - Gravity driven
  - RNG turbulence model with no-slip wall boundary condition
- Boundary conditions:
  - Inflow
    - Connection Tunnel (specify average velocity)
    - Upstream of Lady Bird Lake: velocity and fixed water elevation.
  - Outflow
    - Downstream end of Lady Bird Lake: pressure boundary

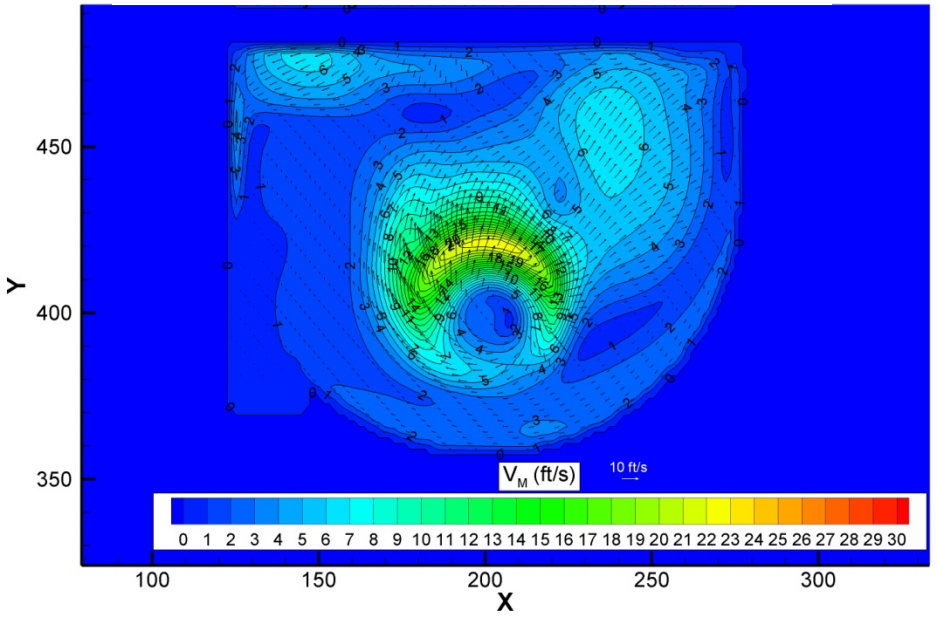
Connection #1: 100-yr flood
3.5 ft/s cross flow No flip bucket Z=415 ft



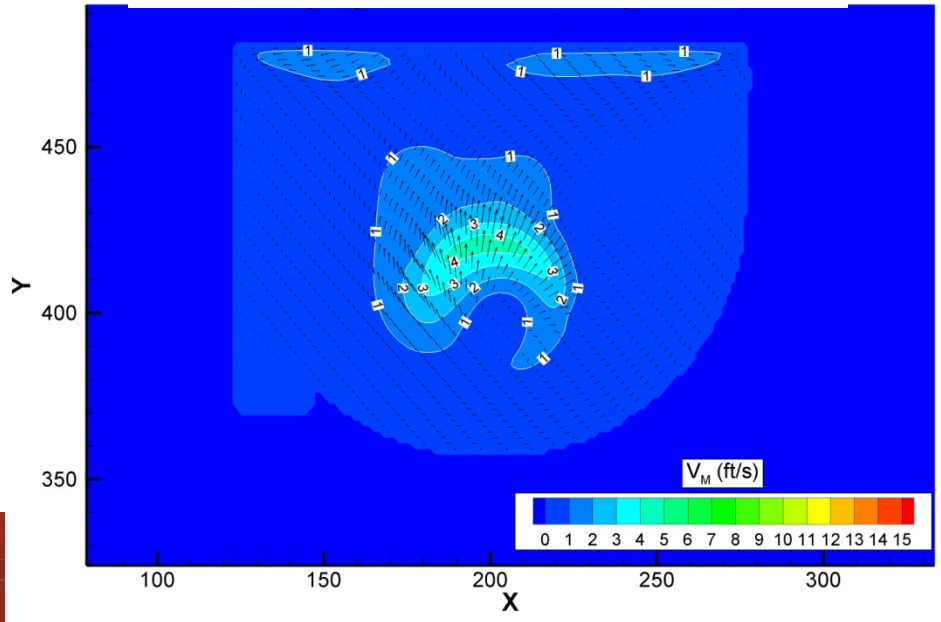
Connection #2: 100-yr flood
3.5 ft/s cross flow 3.5 ft flip bucket Z = 415



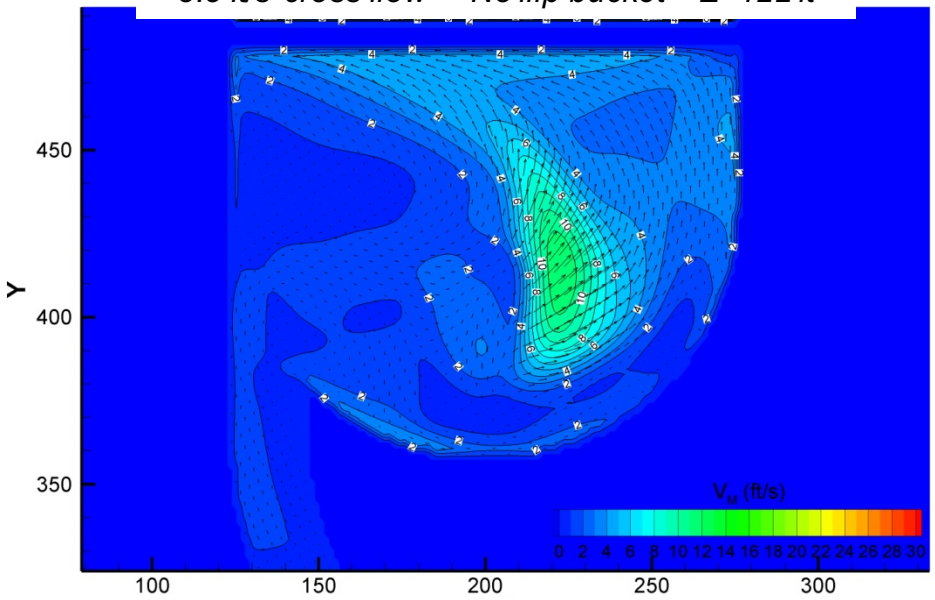
Connection #2: 500-yr flood
3.5 ft/s cross flow 3 ft flip bucket Z = 415



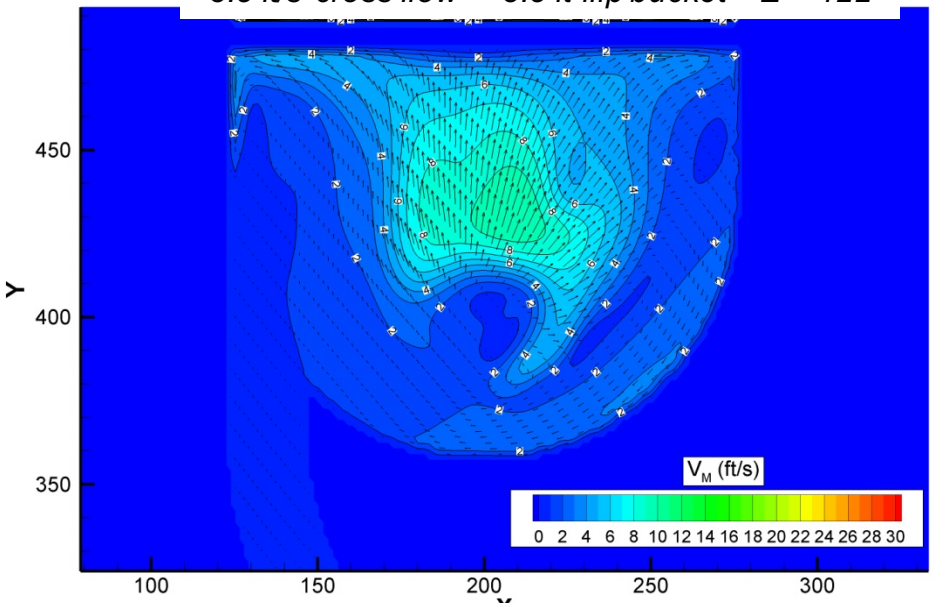
Connection #2: 2-yr flood
1.25 ft/s cross flow 3 ft flip bucket Z = 415



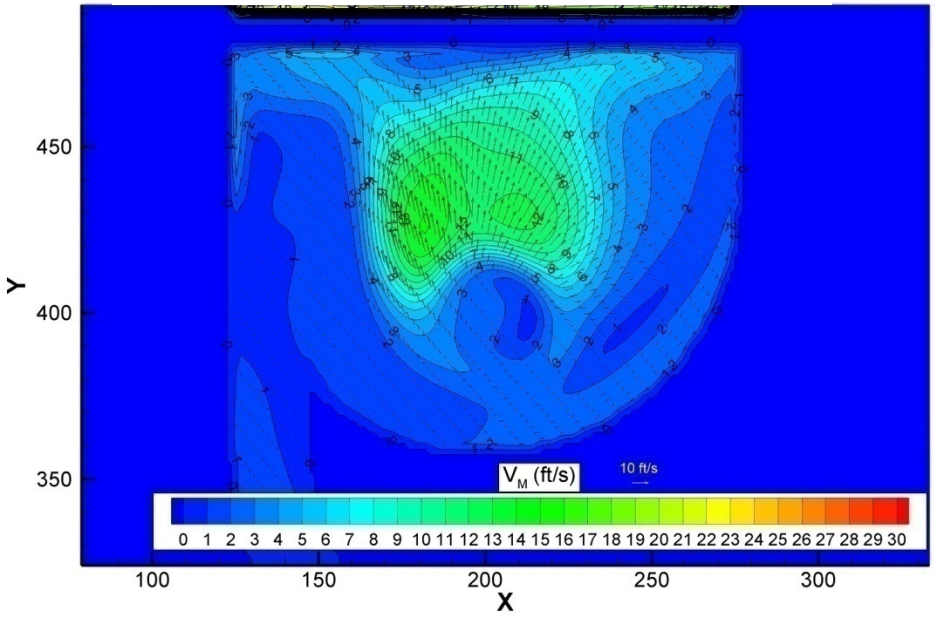
Connection #1: 100-yr flood
3.5 ft/s cross flow No flip bucket Z=422 ft



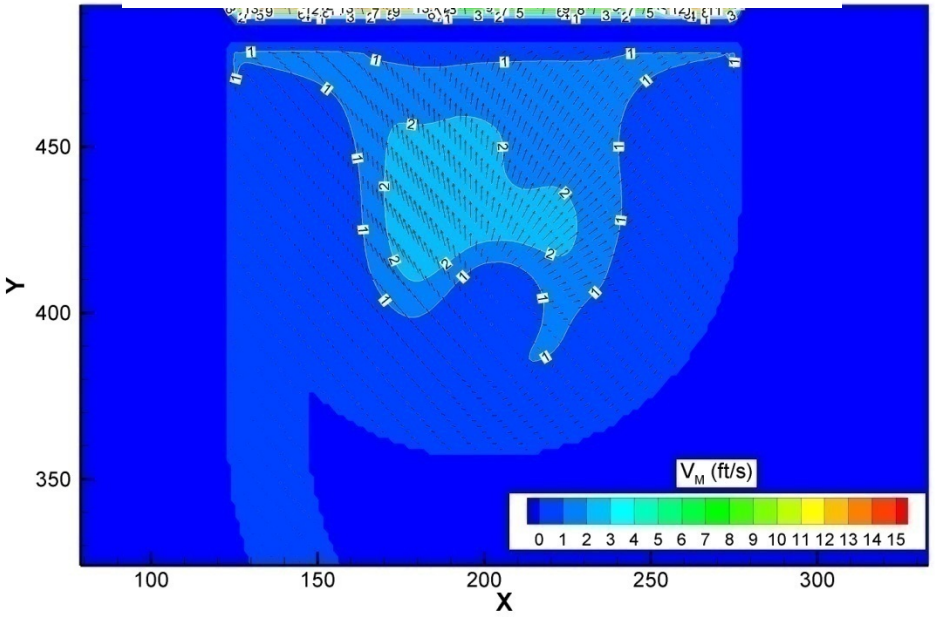
Connection #2: 100-yr flood
3.5 ft/s cross flow 3.5 ft flip bucket Z = 422



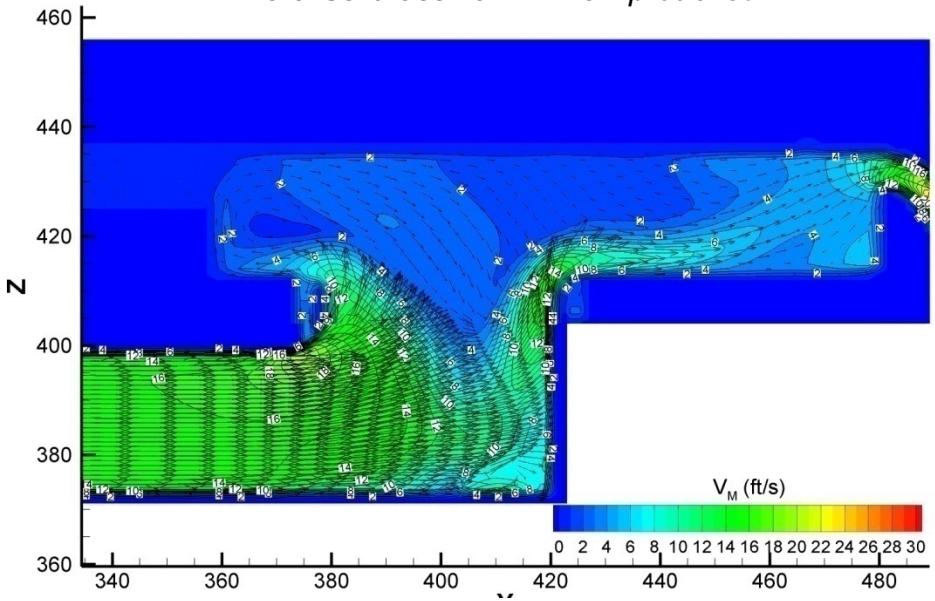
Connection #2: 500-yr flood
3.5 ft/s cross flow 3 ft flip bucket Z = 422



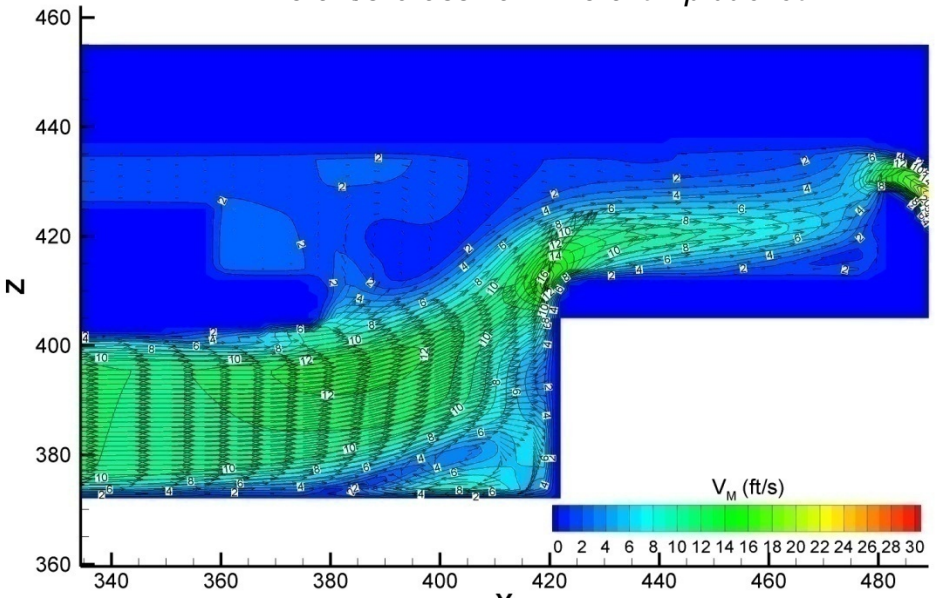
Connection #2: 2-yr flood
1.25 ft/s cross flow 3 ft flip bucket Z = 422



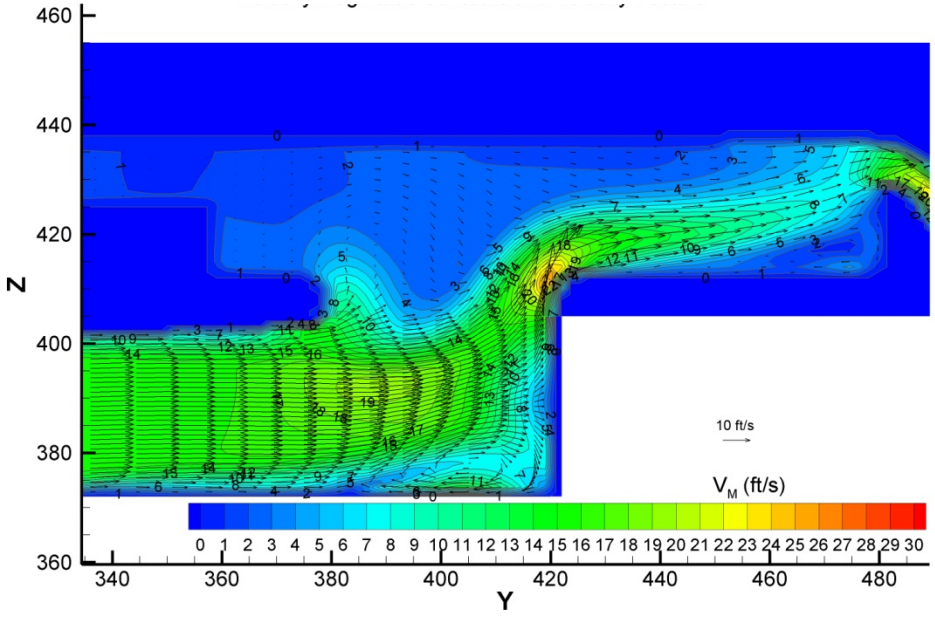
Connection #1: 100-yr flood
3.5 ft/s cross flow No flip bucket



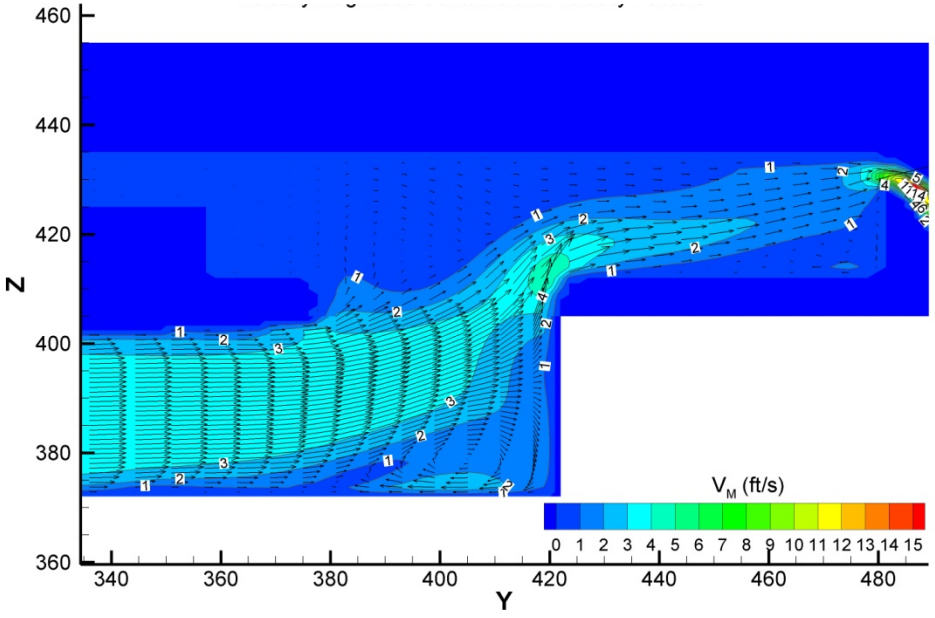
Connection #2: 100-yr flood
3.5 ft/s cross flow 3.5 ft flip bucket



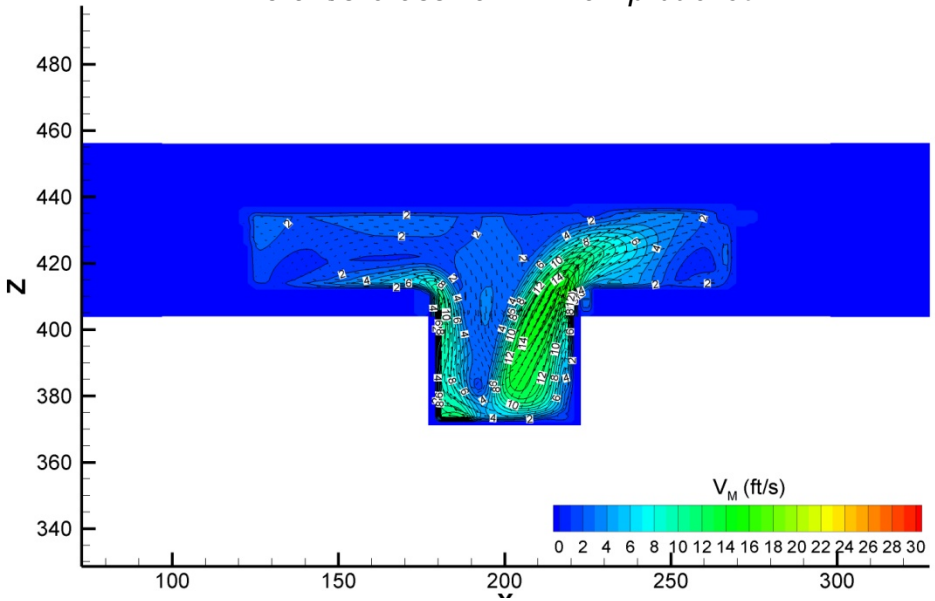
Connection #2: 500-yr flood
3.5 ft/s cross flow 3 ft flip bucket



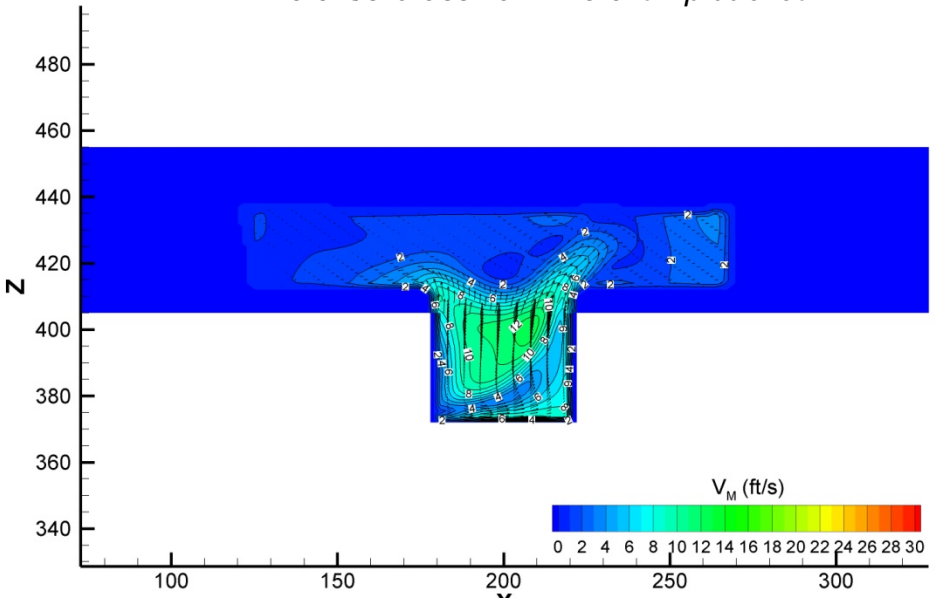
Connection #2: 2-yr flood
1.25 ft/s cross flow 3 ft flip bucket



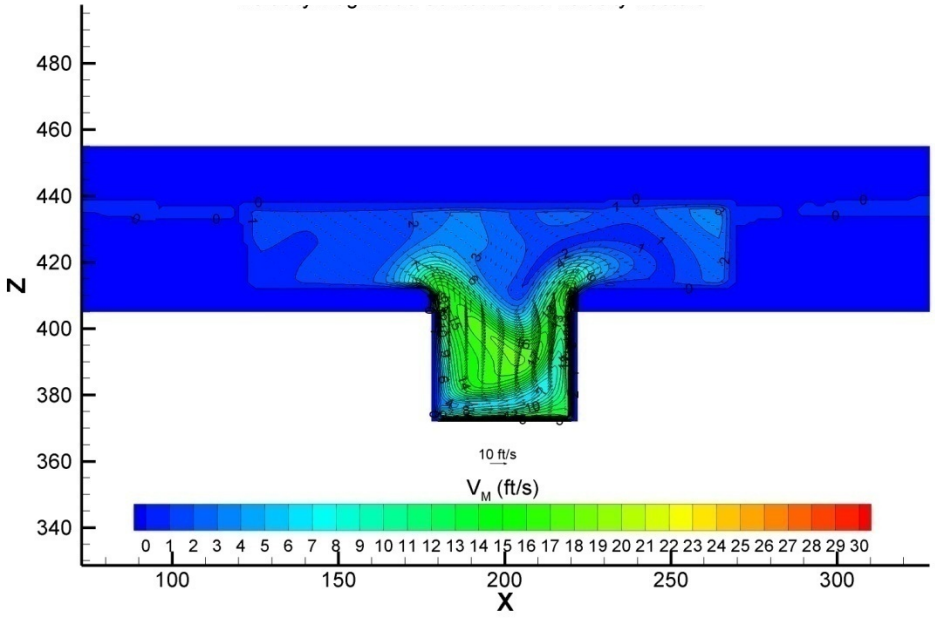
Connection #1: 100-yr flood
3.5 ft/s cross flow No flip bucket



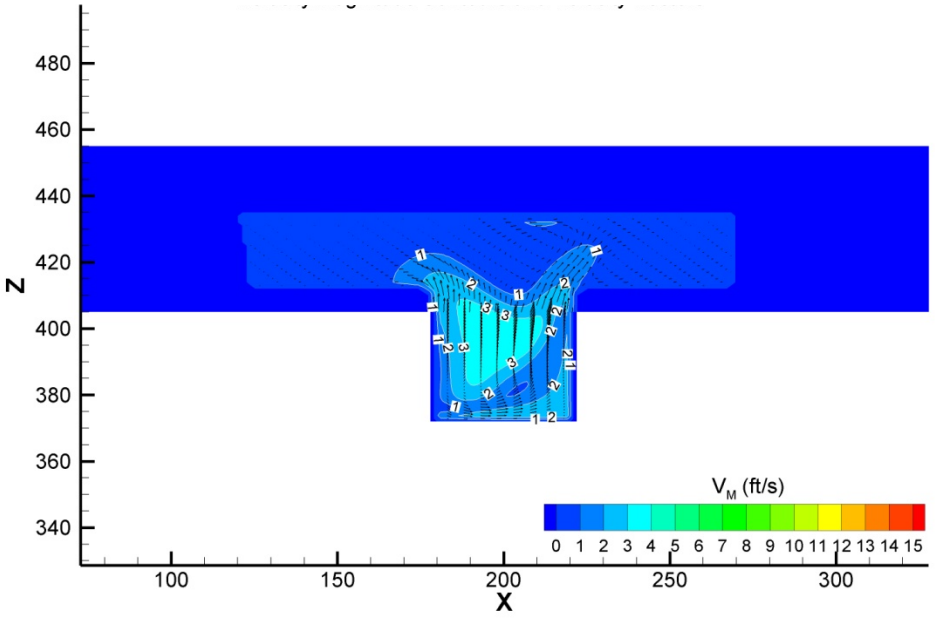
Connection #2: 100-yr flood
3.5 ft/s cross flow 3.5 ft flip bucket



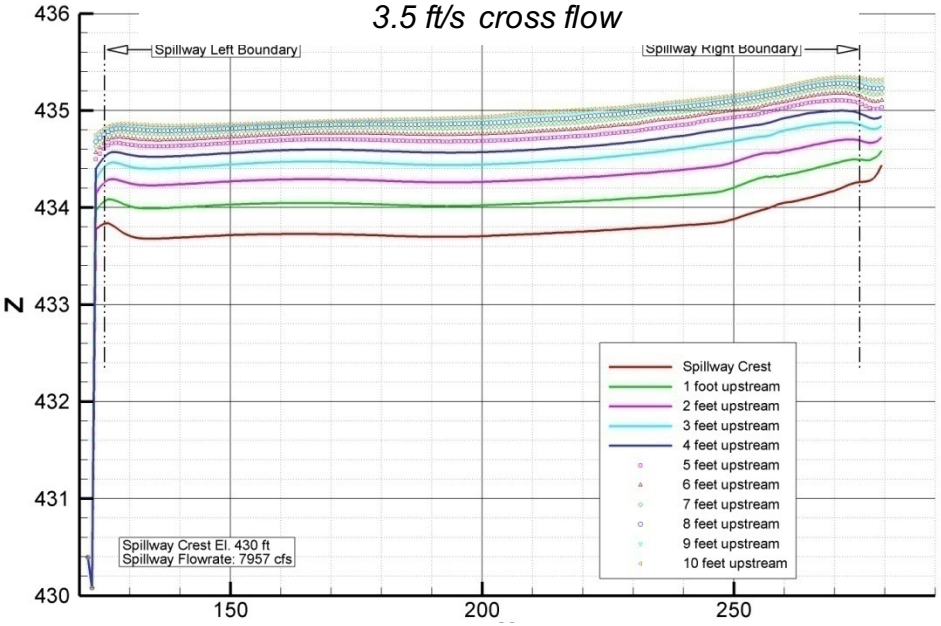
Connection #2: 500-yr flood
3.5 ft/s cross flow 3 ft flip bucket



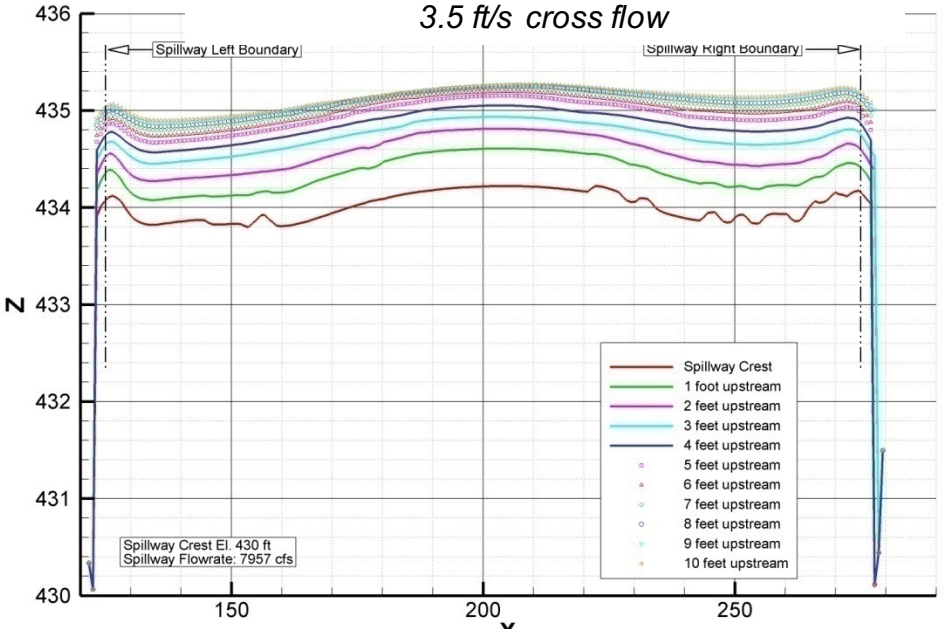
Connection #2: 2-yr flood
1.25 ft/s cross flow 3 ft flip bucket



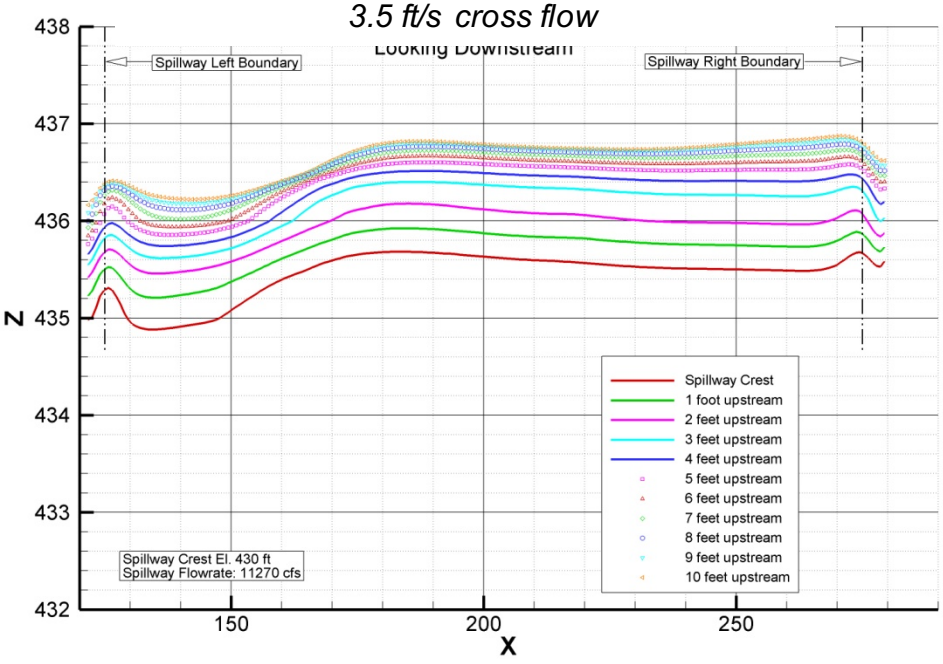
Connection #1: 100-yr flood
3.5 ft/s cross flow



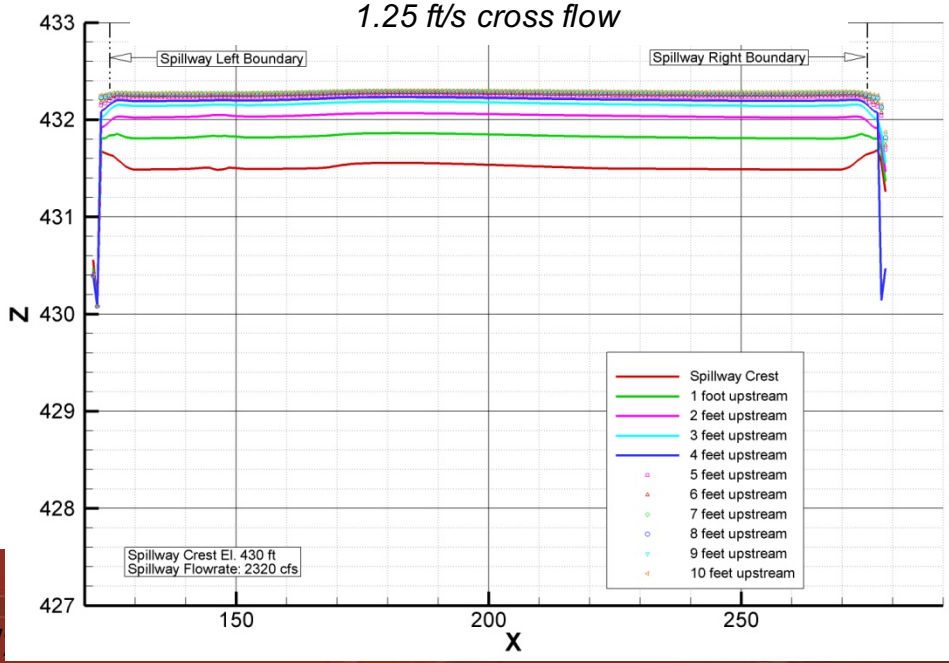
Connection #2: 100-yr flood
3.5 ft/s cross flow



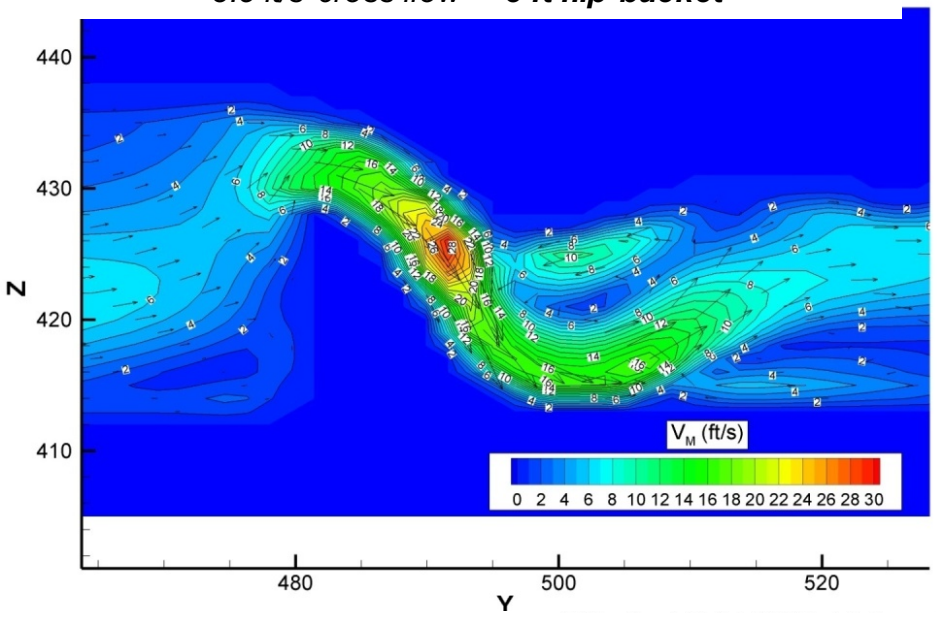
Connection #2: 500-yr flood
3.5 ft/s cross flow



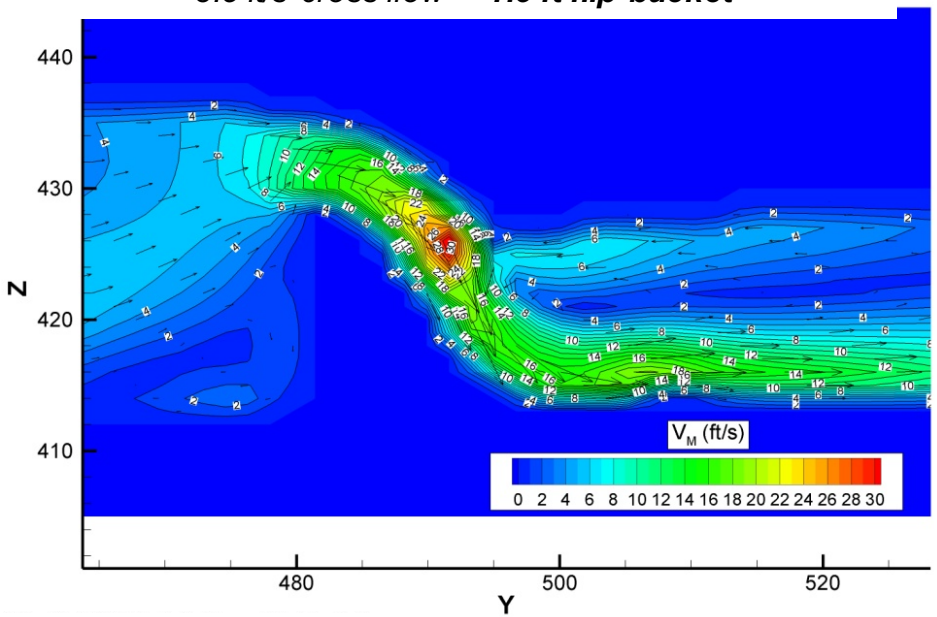
Connection #2: 2-yr flood
1.25 ft/s cross flow



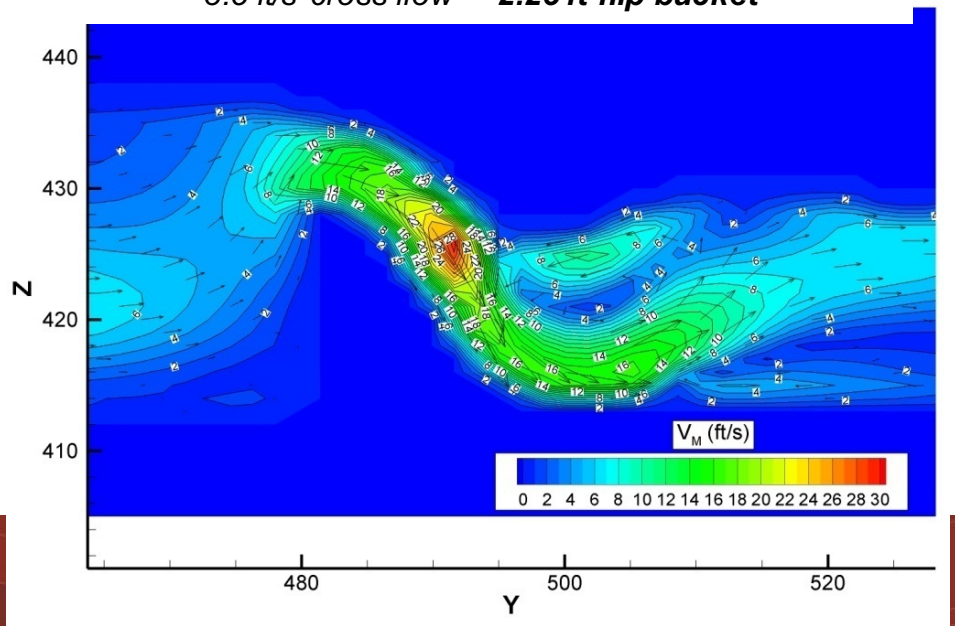
Connection #2: 100-yr flood
3.5 ft/s cross flow ***3 ft flip bucket***



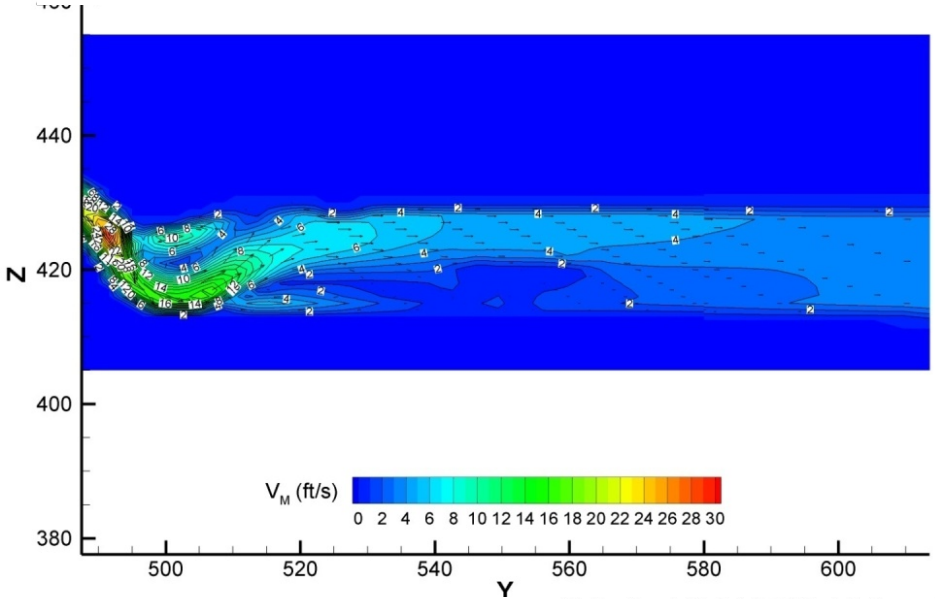
Connection #2: 100-yr flood
3.5 ft/s cross flow ***1.5 ft flip bucket***



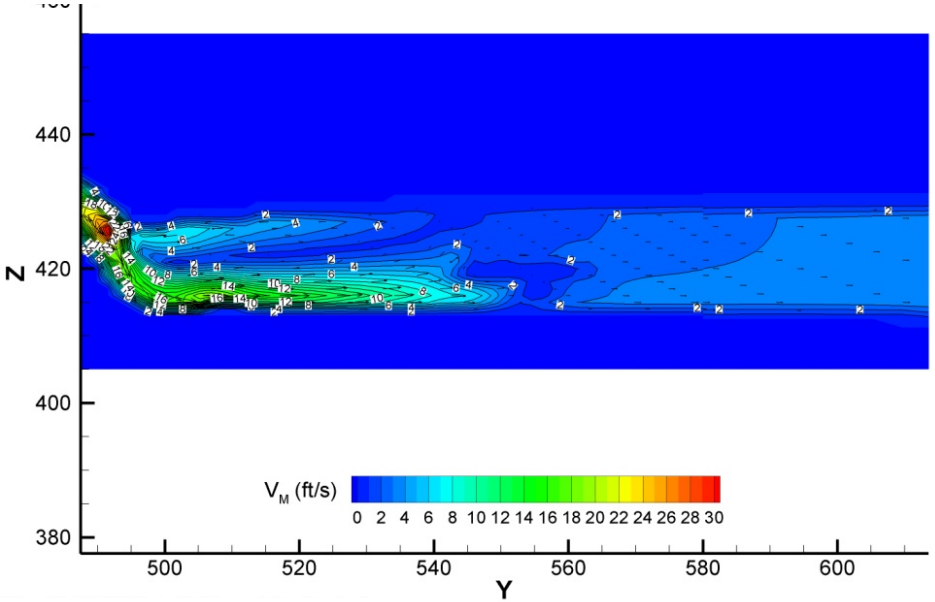
Connection #2: 100-yr flood
3.5 ft/s cross flow ***2.25 ft flip bucket***



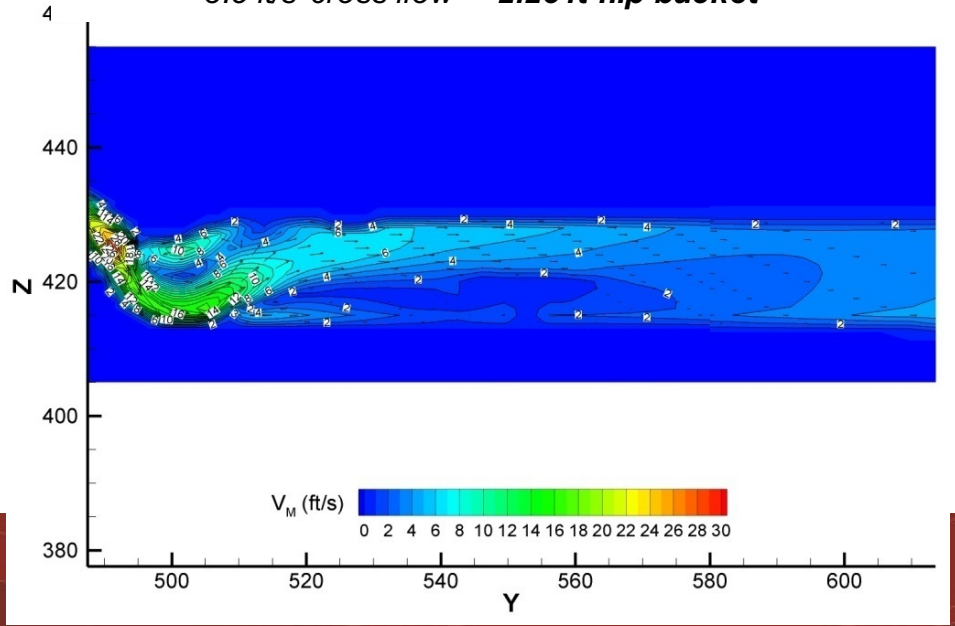
Connection #2: 100-yr flood
3.5 ft/s cross flow ***3 ft flip bucket***



Connection #2: 100-yr flood
3.5 ft/s cross flow ***1.5 ft flip bucket***



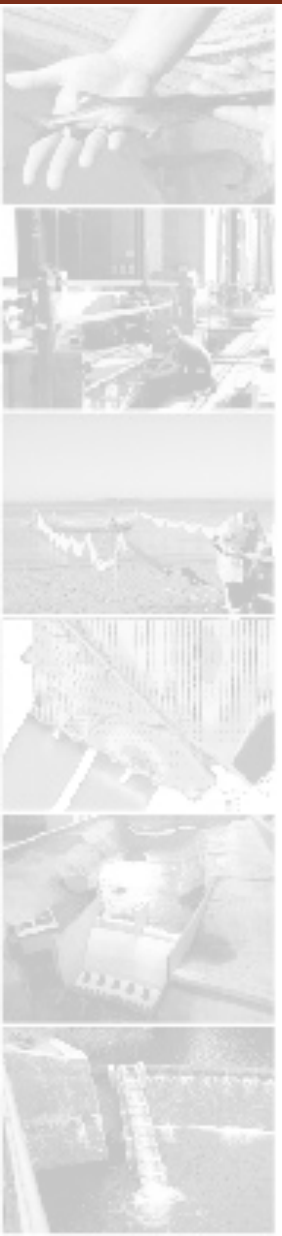
Connection #2: 100-yr flood
3.5 ft/s cross flow ***2.25 ft flip bucket***



Pressure Force on Pipe Riser and Water Intake Screen

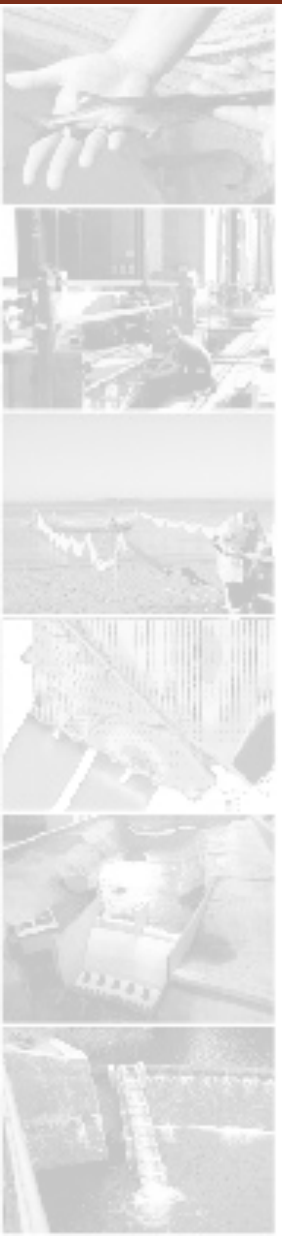
	X-Force (lbf)	Y-Force (lbf)	Z-Force (lbf)	Total (lbf)
Run 2, Connection #1, 100-yr flood, 3.5 ft/s cross flow, No spillway flip bucket	757	1191	-644	1561
Run 3, Connection #2, 100-yr flood, 3.5 ft/s cross flow, 3' spillway flip bucket	1446	-107	-1213	1901
Run 4, Connection #2, 500-yr flood, 3.5 ft/s cross flow, 3' spillway flip bucket	1040	547	-1056	1580
Run 5, Connection #2, 2-yr flood, 1.25 ft/s cross flow, 3' spillway flip bucket	1774	-622	-622	1895
Run 6, Connection #2, 100-yr flood, 3.5 ft/s cross flow, 1.5' spillway flip bucket	1651	1208	-776	2204
Run 7, Connection #2, 100-yr flood, 3.5 ft/s cross flow, 2.25' spillway flip bucket	1470	-163	-1218	1919

Physical Model Inlet, Tunnel and Outlet



Objectives:

1. Using Final Design from CFD models, Conduct Further Evaluation of flow patterns and phenomena which cannot be conducted using CFD.
    - Rating Curves (Water levels versus Flows)
    - Junction Losses
    - Vortexing
    - Air Entrainment
    - Fluctuating Pressures at Tunnel Portal
2. Design any additional modifications if required.



Physical Model Design

Similitude Requirements

The physical model is operated based on Froude similitude.

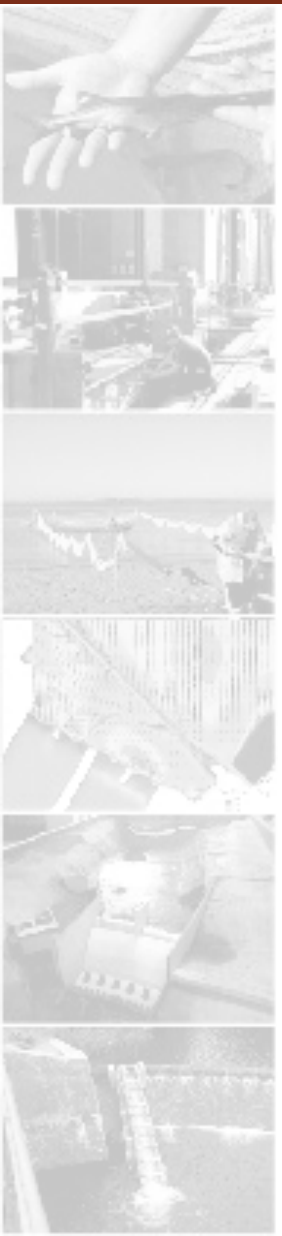
The Froude number represents the ratio of inertial forces to gravitational forces. Correct similitude dictates:

$$(\text{Froude No.})_{\text{Model}} = (\text{Froude No.})_{\text{Prototype}}$$

or

$$V_r/(g_r L_r)^{0.5} = 1,$$

where r denotes model to prototype ratio



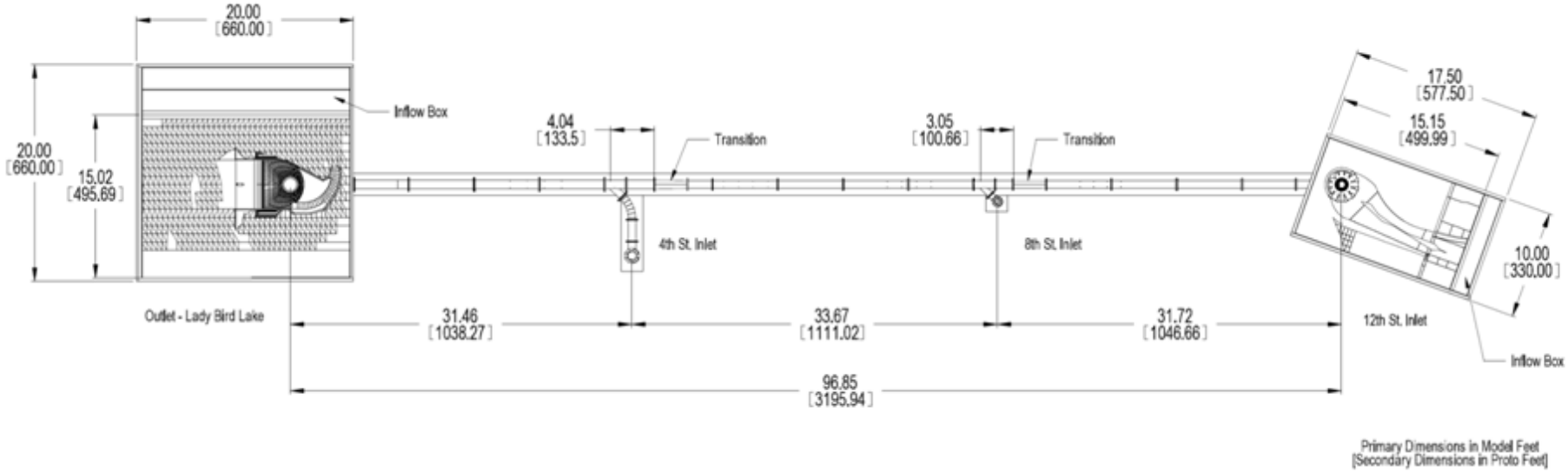
Physical Model Design & Construction

- Model scale was selected to provide turbulent flow as in the prototype,
- Tunnel friction cannot be scaled. Model simulates a reduced length of tunnel with loss orifice plates (if required) to simulate HGL provided for the 100 yr event Entire length of tunnel is not required to satisfy the objectives of the study.
- Screen simulation is such that the porosity and loss coefficient is approximately equal to that in the prototype and provided similar flow guidance.
- Geometric Scale, $L_r = L_m/L_p = 1/33$
- Velocity Scale, $V_r = L_r^{0.5} = 1/5.74$
- Flow Rate Scale, $Q_r = L_r^{2.5} = 1/6255$
- Time Scale, $T_r = L_r^{0.5} = 1/5.74$
- Pressure Scale, $p_r = p_m/p_p = 1/33$

Physical Model Limitations

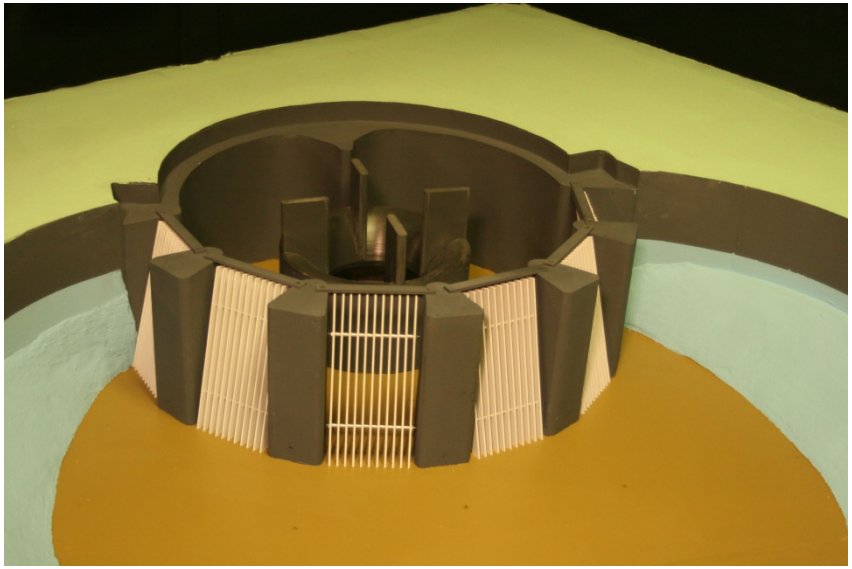
- Tunnel friction cannot be scaled. Model simulates a reduced length of tunnel with loss orifice plates (if needed) to simulate HGL provided for the 100 yr event Entire length of tunnel is not required to satisfy the objectives of the study.
- The flow over the spillway and the upstream water surface elevations in the channel as well as the controlled water level in the outlet structure will not be affected by the HGL, the model can be used to develop rating curves.
- The bubbles sizes, pressures that affect their sizes, the bubble rise velocities and the two–phase flow regime are not exactly simulated in the model. Nevertheless, the data obtained from measurements of air concentrations (volume fractions) in the model would provide useful information towards determining the likely air entrainment in the tunnel in conjunction with further calculations based on literature.
- Even though the air entrainment generated by jet impact inside the morning-glory shaft is mainly a function of Froude number, any measured air concentrations or volume fractions of air in the model tunnel would not exactly duplicate those in the prototype due to possible air entrainment scale effects in the reduced scale model resulting from significantly lower impingement velocities in the model shaft.

Physical Model Design & Construction



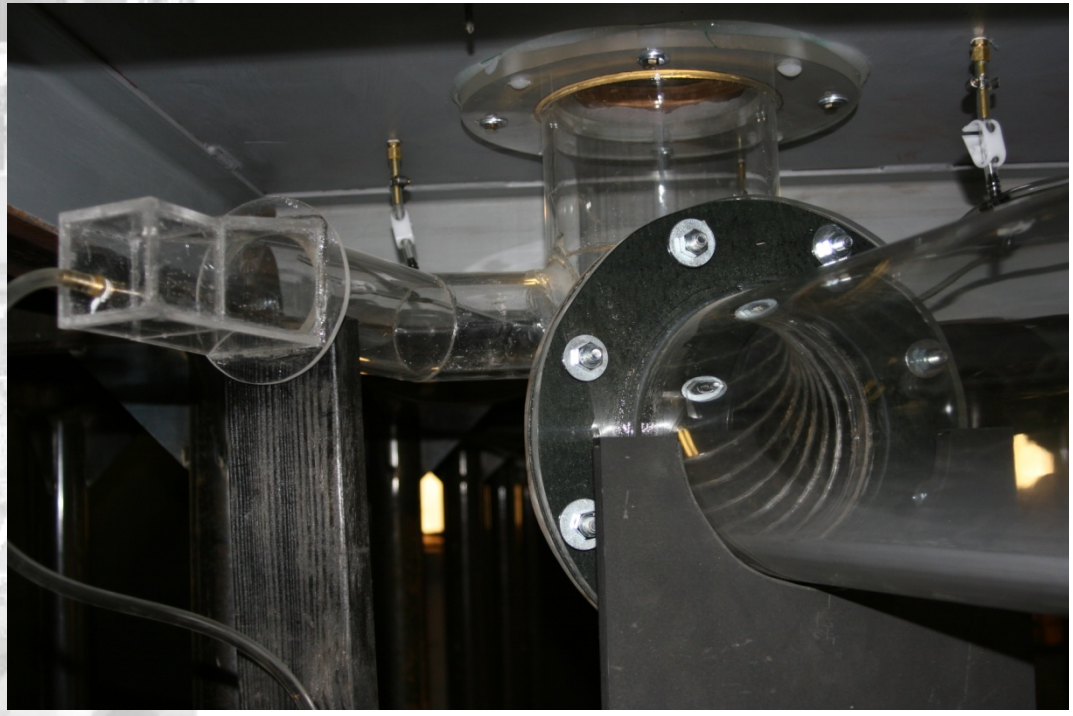
Physical Model Design & Construction

Inlet Model



Morning Glory Spillway And Screens

Physical Model Design & Construction



Spillway to Tunnel Transition And Portal

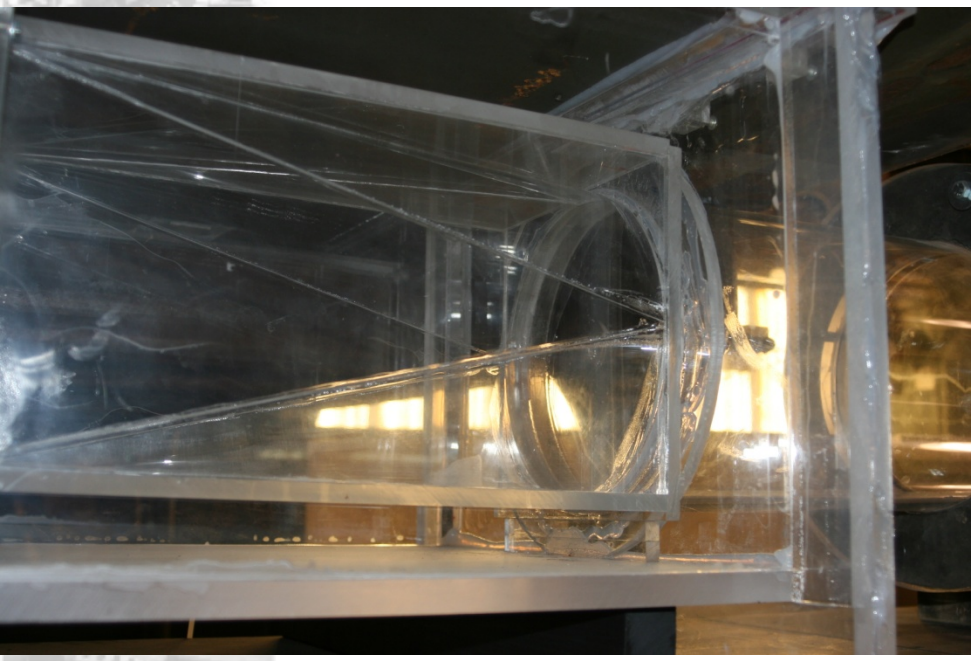
Tunnel

Physical Model Design & Construction

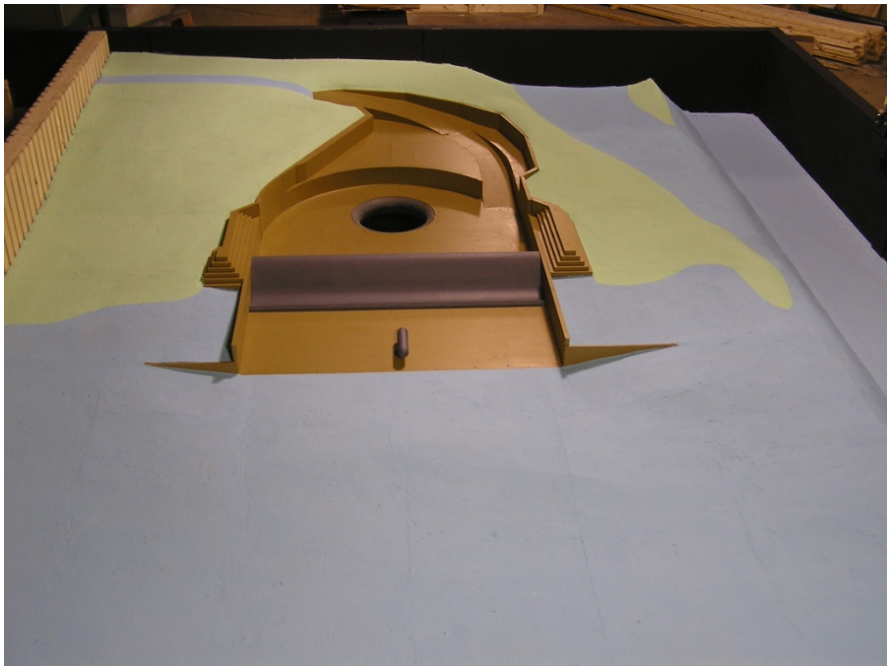
8th Street Lateral Junction

4th Street Lateral Junction

Physical Model Design & Construction

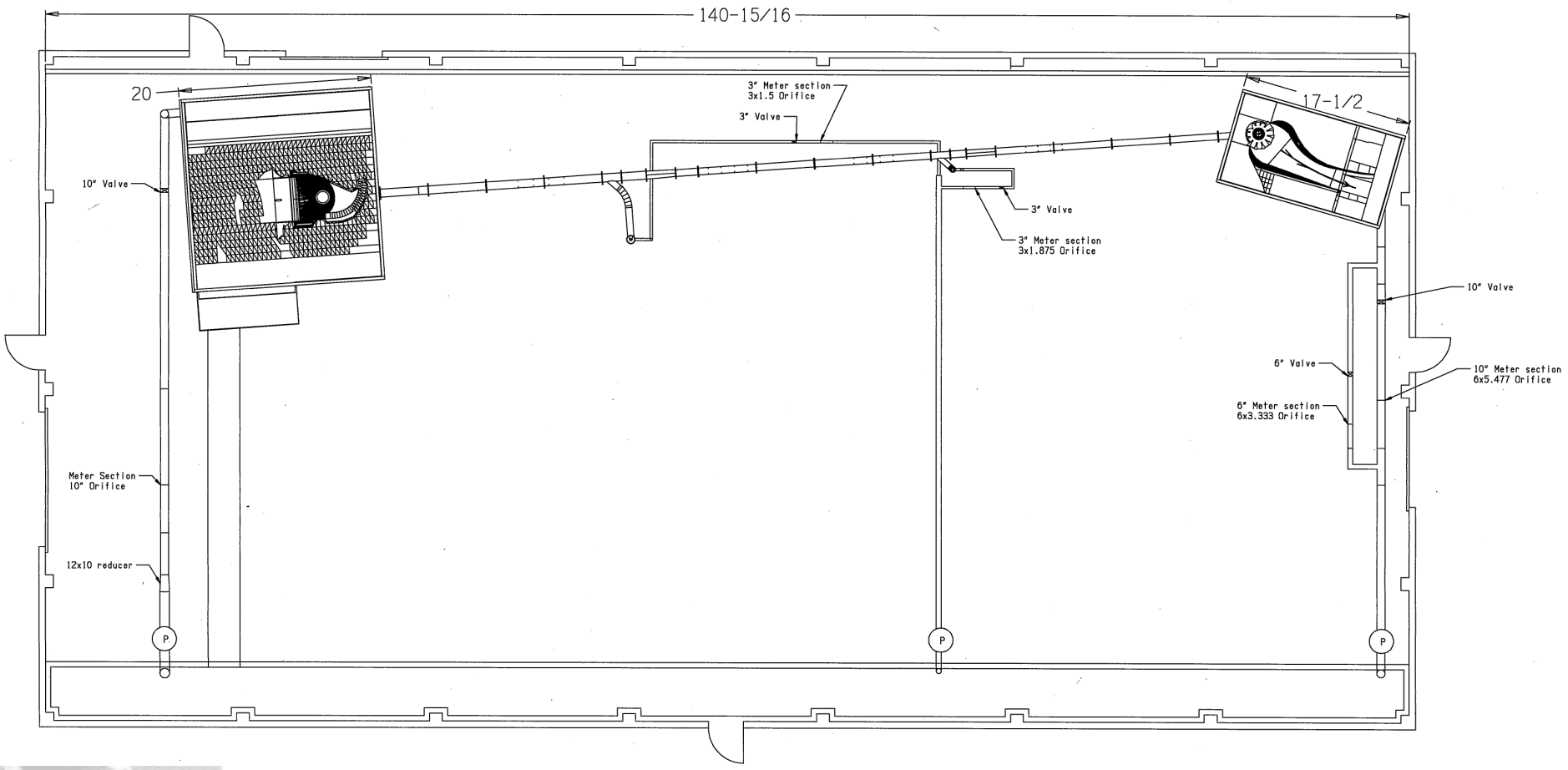


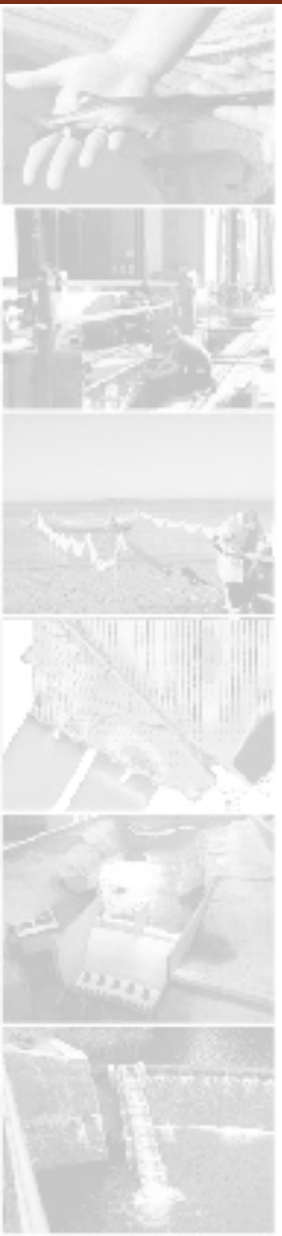
Outlet Transition



Outlet Structure

Model Flow Loop





Lets Go Look at the Model!

Testing
Test Matrix

Peak Tunnel/Peak Intervening						
Event	12th St Inlet (cfs)	8th St Lateral (cfs)	4th St Lateral (cfs)	Total Outlet (cfs)	LBL Cross Velocity (ft/sec)	LBL WL (ft)
500 yr	11,111	1,278	1,313	13,702	3.5	428
100 yr	8,247	960	1,001	10,208	3.5	428
50 yr	7,140	832	877	8,849	3.5	428
25 yr	6,151	712	763	7,626	3.5	428
10 yr	4,784	562	619	5,965	3.5	428
5 yr	3,873	452	515	4,840	3.5	428
2 yr	2,543	302	369	3,214	3.5	428
Lagging Tunnel/Peak Intervening						
Event	12th St Inlet (cfs)	8th St Lateral (cfs)	4th St Lateral (cfs)	Total Outlet (cfs)	LBL Cross Velocity (ft/sec)	LBL WL (ft)
100 yr	5,642	960	1,001	7,603	3.5	428

Testing

- **EVALUATE HYDRAULIC PERFORMANCE IN TERMS OF:**

-Air Entrainment (Qualitative)

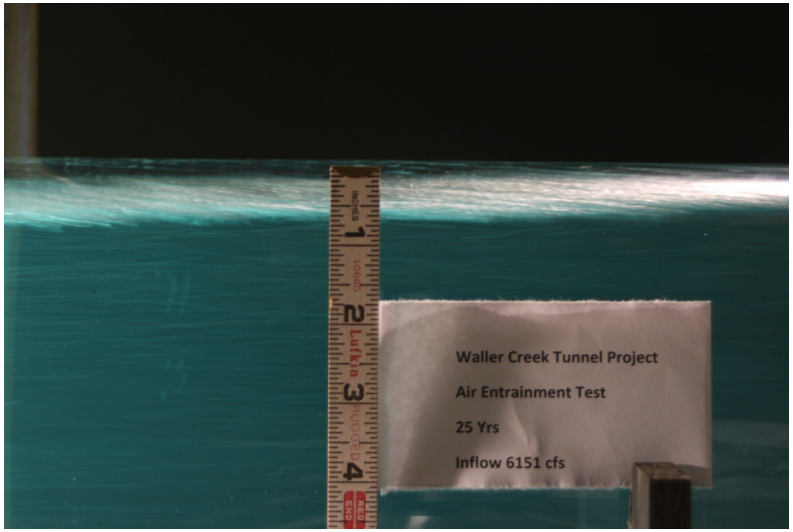
-Rating Curves (Water levels versus Flows)

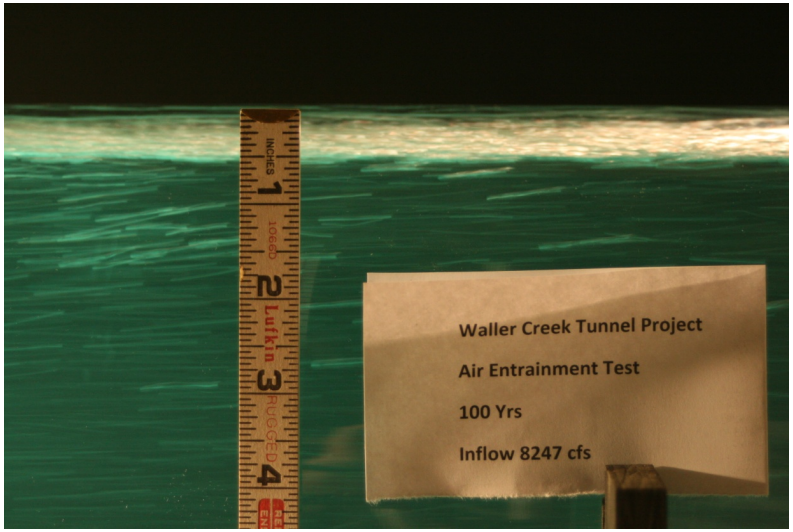
-Junction Losses

-Vortex Formation

-Fluctuating Pressures at Tunnel Portal

Testing





	25yr	100yr
Q_w (cfs)	0.98	1.32
P(inches)	18.17	18.63
P(psi)	0.66	0.67
P(psia)	15.36	15.37
Air Density (slugs/ft3)	0.002479	0.002482
Avg. A_w (in^2)	40.89	41.35
Avg. A_a (in^2)	2.14	1.69
Avg. $VF_{a\ model} = A_a/A_{a+}A_w$	0.05	0.04
Avg. $VF_{a\ model}$ (%)	5.0	3.9
Max. A_w (in^2)	39.53	40.45
Max. A_a (in^2)	3.50	2.59
Max. $VF_{a\ model} = A_a/A_{a+}A_w$	0.08	0.06
Max. $VF_{a\ model}$ (%)	8.1	6.0

Where:

Air Temp (^oF)	60
Water Temp (^OF)	60
Atm P (psia)	14.7
Water Density ($slugs/ft^3$)	1.938
Air Density ($slugs/ft^3$)	0.002373

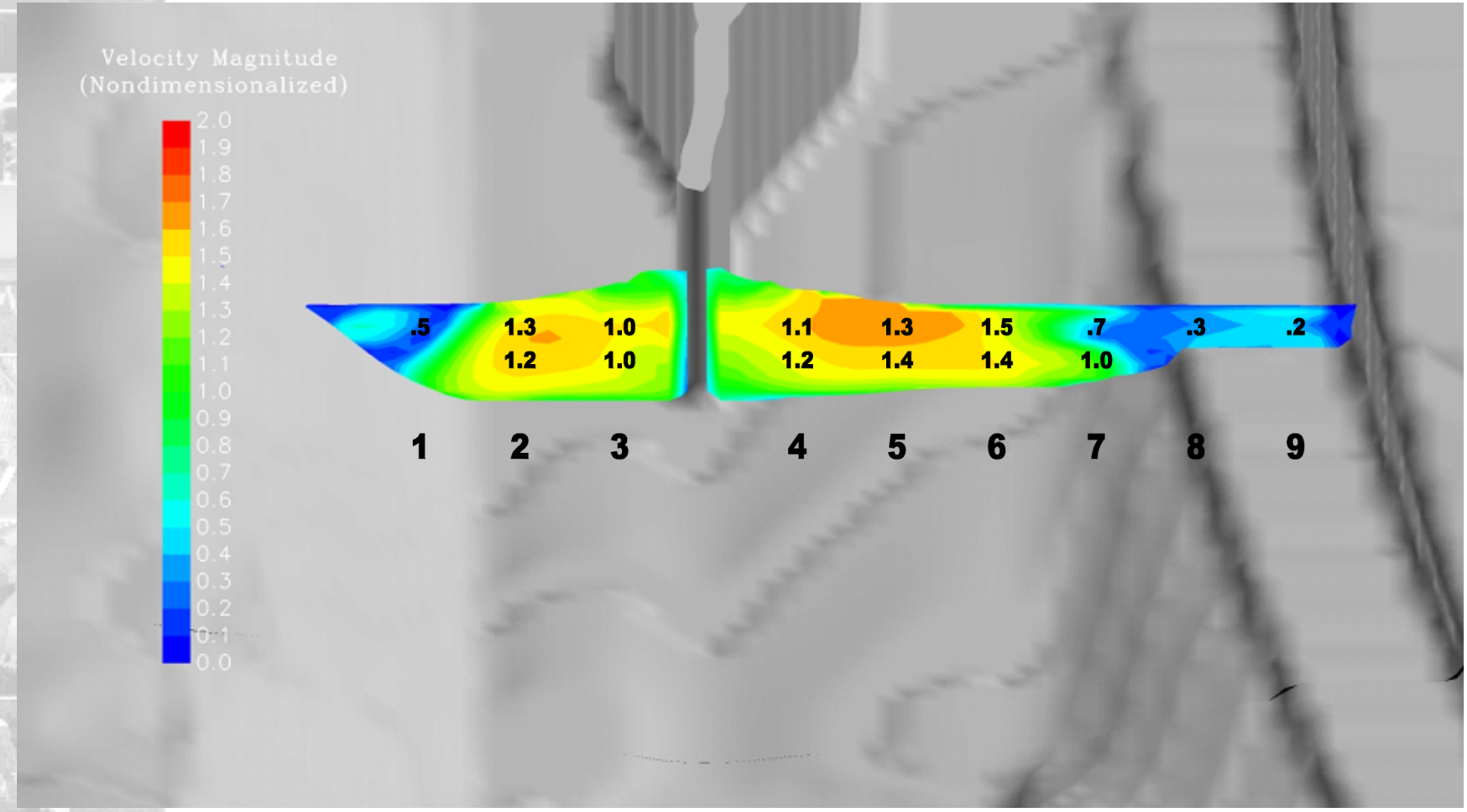
Model Validation

Confirm model HGL:

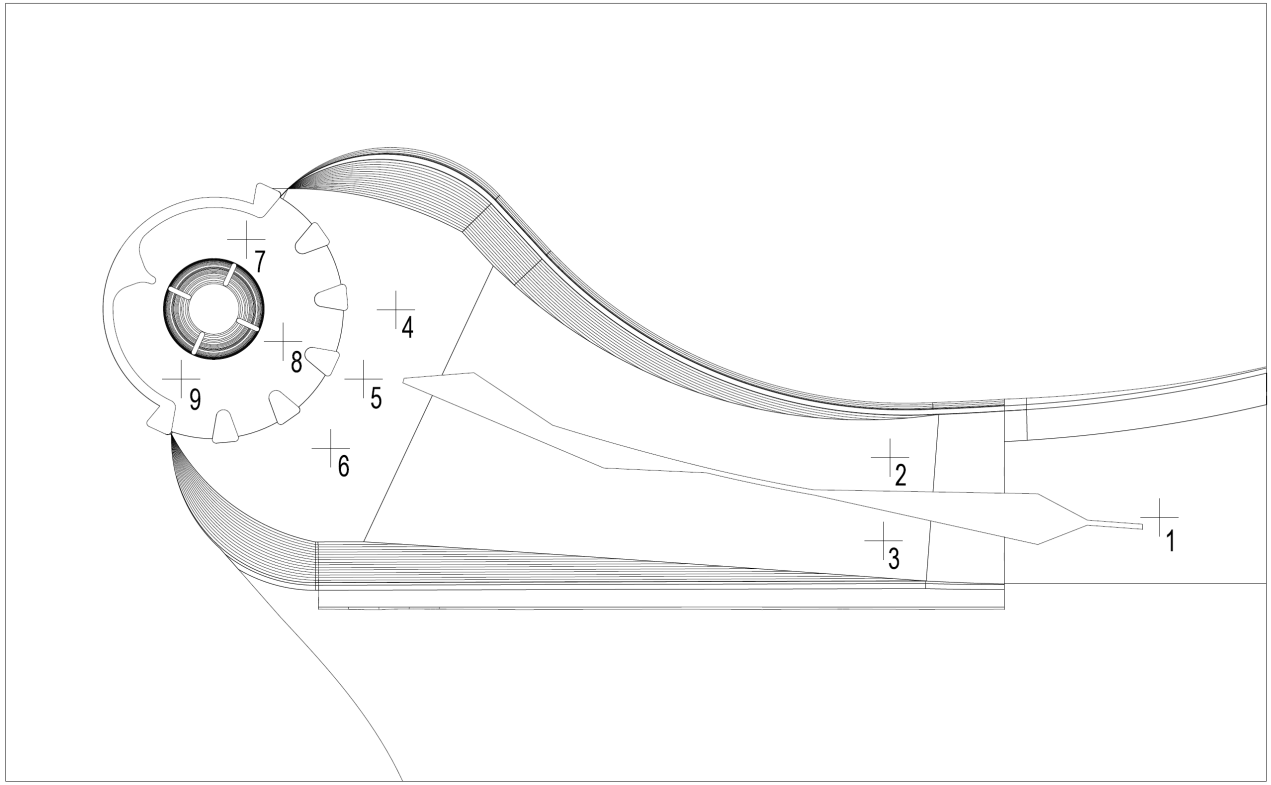
With Orifice Plates Installed @ 100yr Peak/Peak
HGL = 476.8

With Orifice Plates Removed @ 100yr Peak/Peak
HGL = 473.5

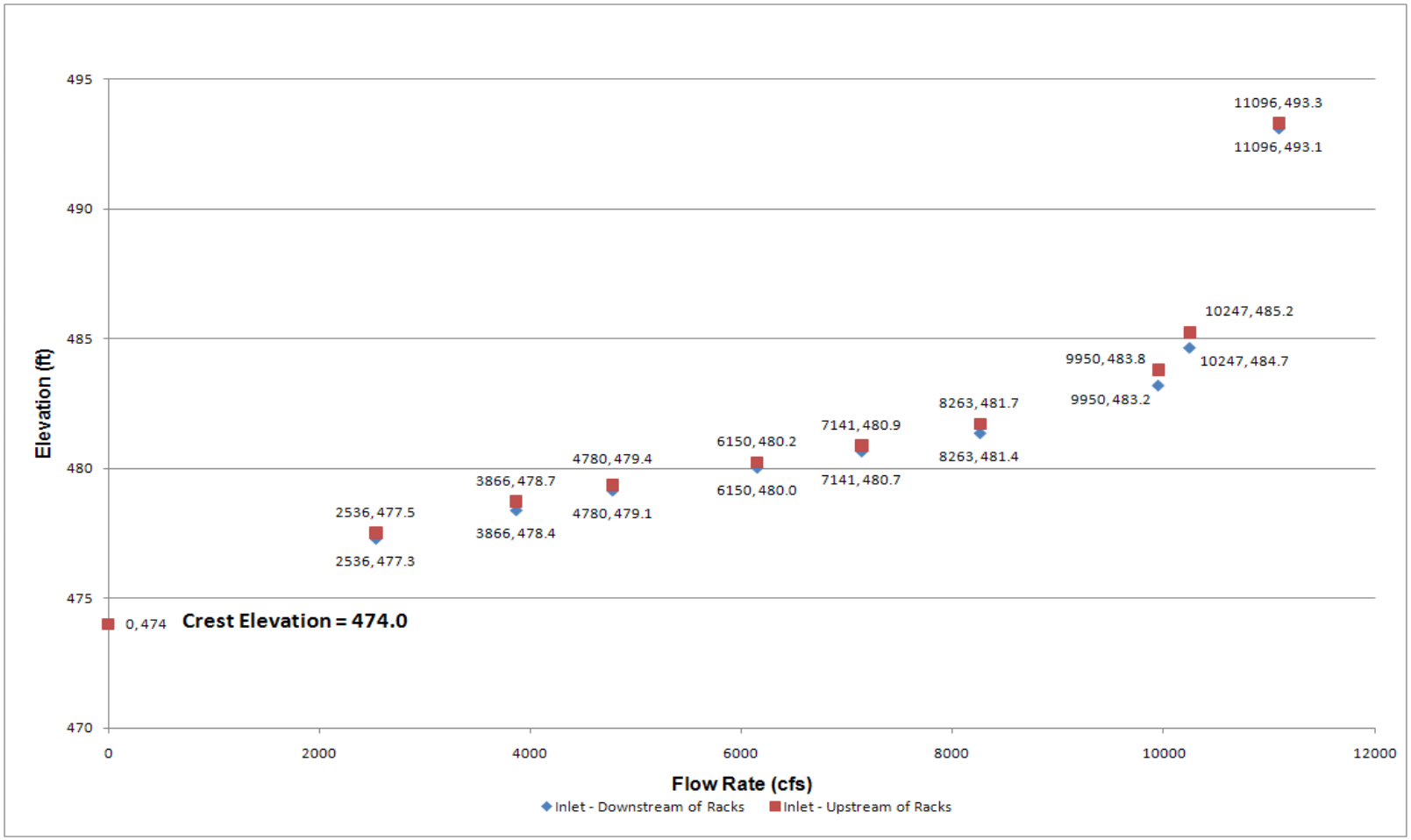
Model Validation



Testing



Testing
Morning Glory Inlet Rating Curve

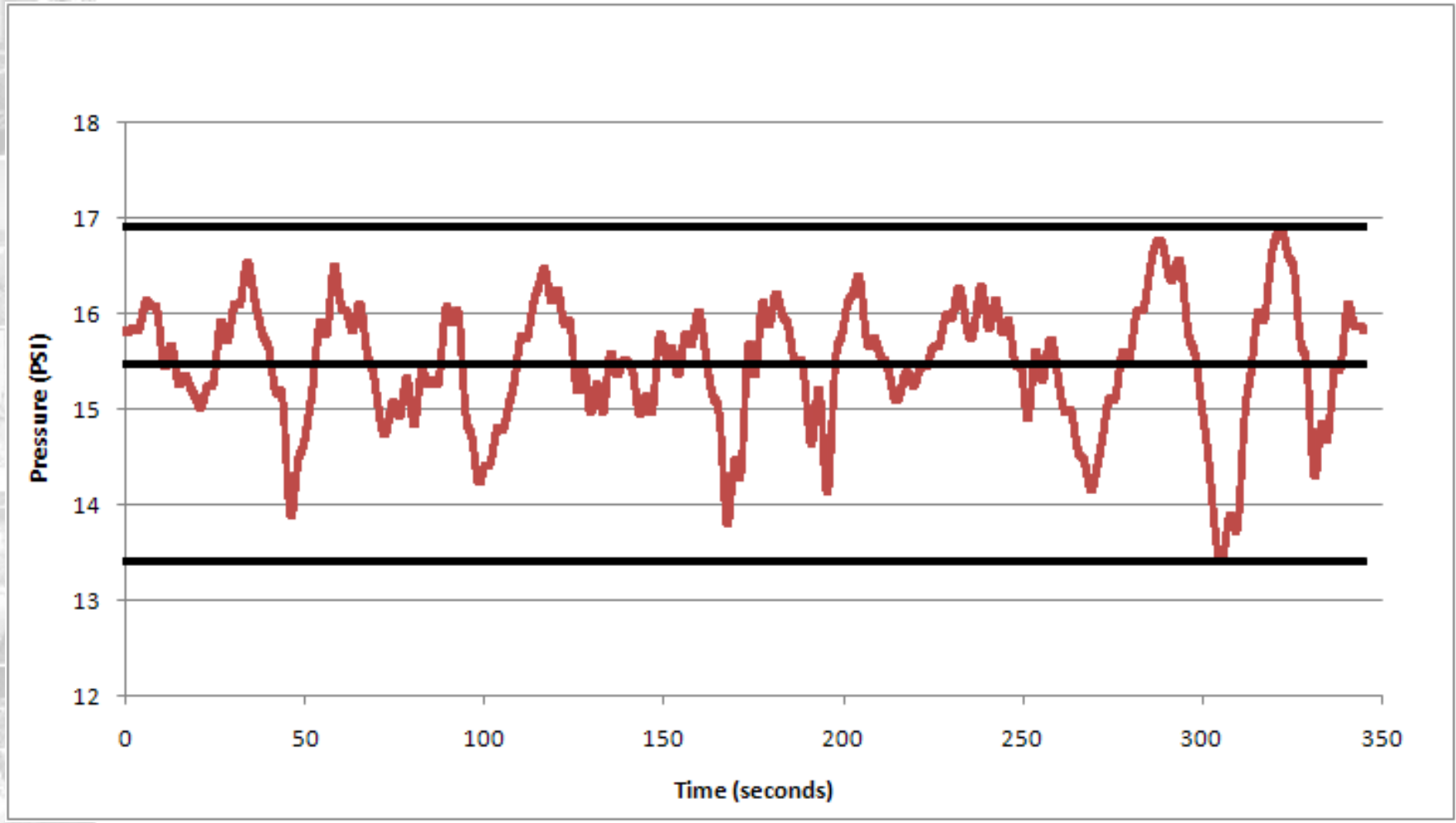


Testing
Morning Glory Inlet Rating Curve HGL Sensitivity

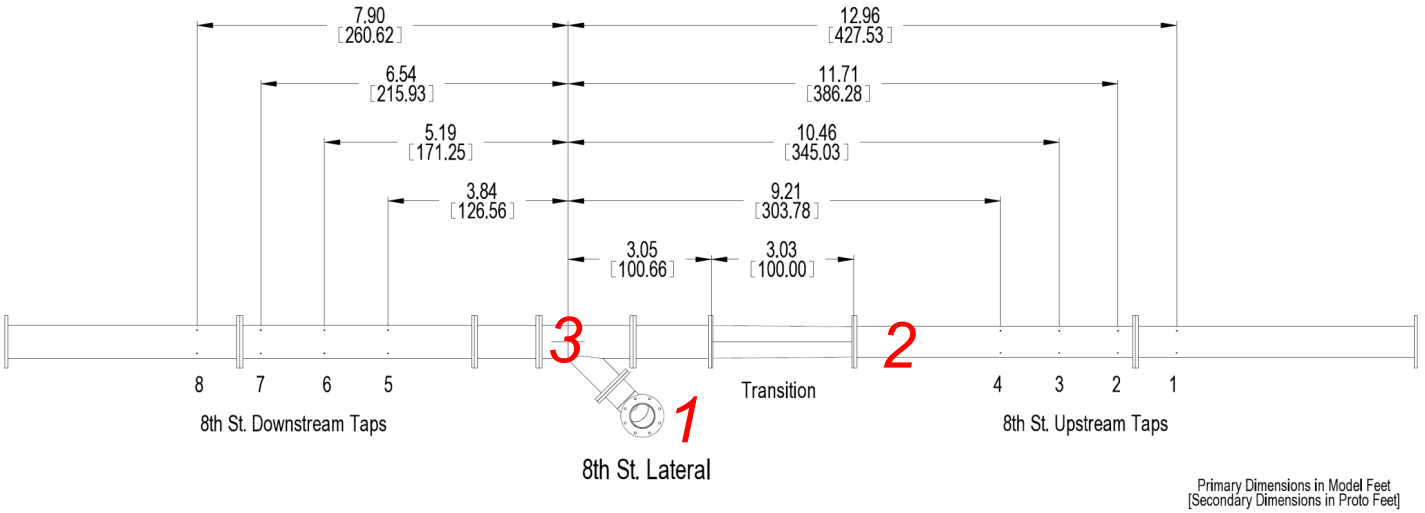
100 yr Event (Q_{inlet} = 8247cfs)

HGL	U.S. of Racks (El. Ft)	D.S. of Racks (El. Ft)
473.5	481.7	481.4
478.2	481.7	481.4
479.7	481.8	481.5

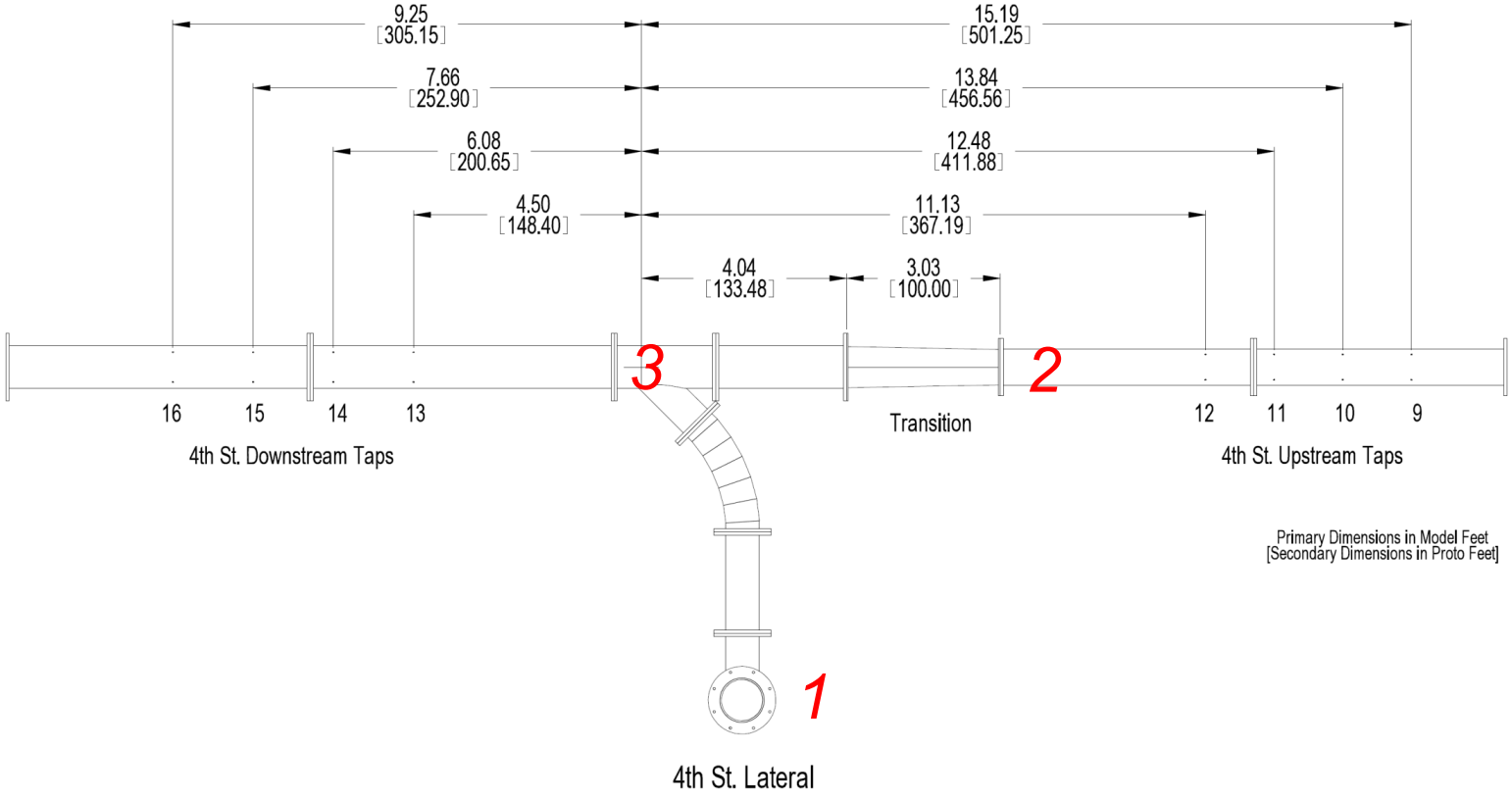
Testing
Pressure Fluctuation at Portal



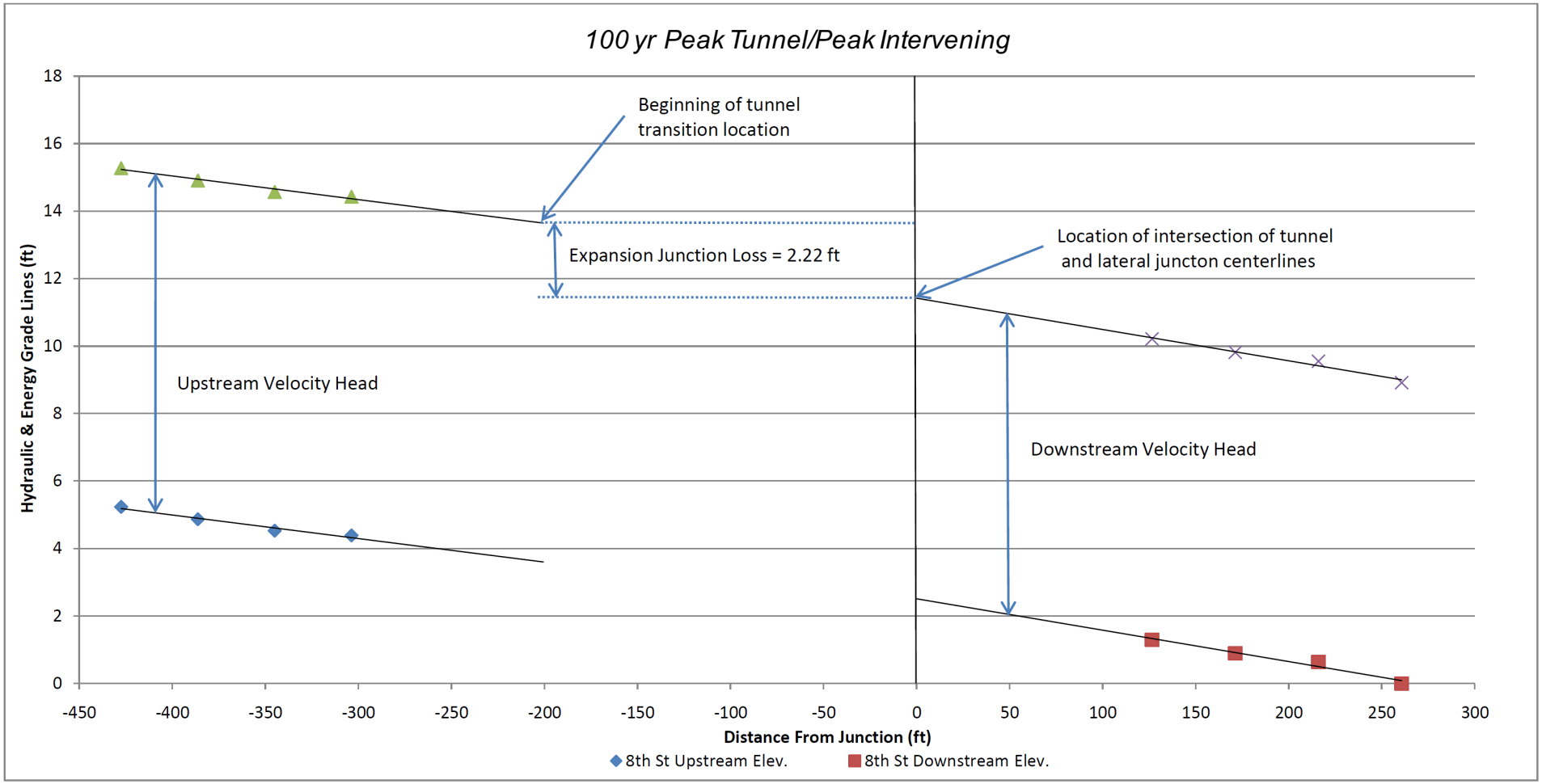
Testing
Lateral Junction Loss Coefficients



Testing
Lateral Junction Loss Coefficients



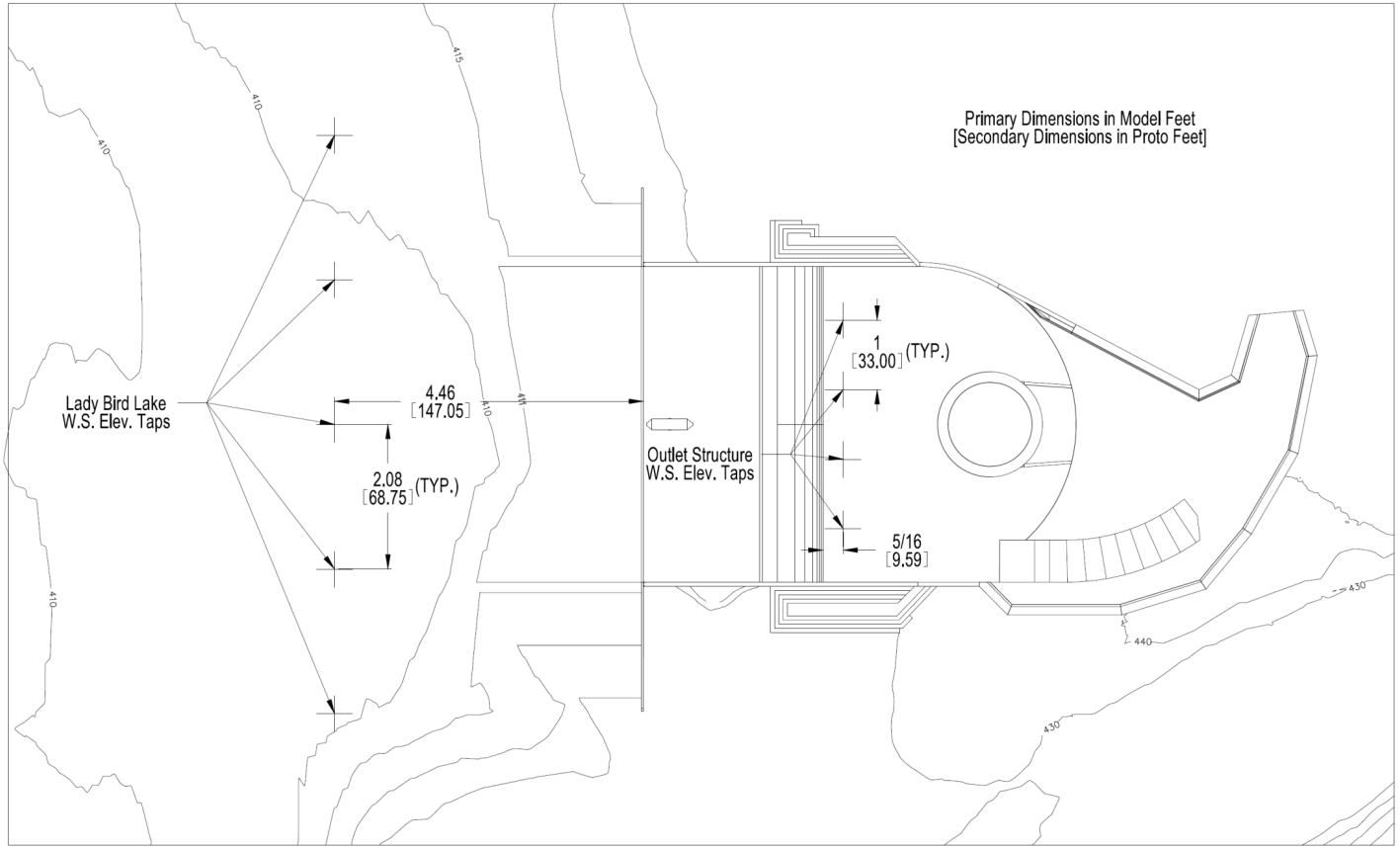
Testing
Lateral Junction Loss Coefficients



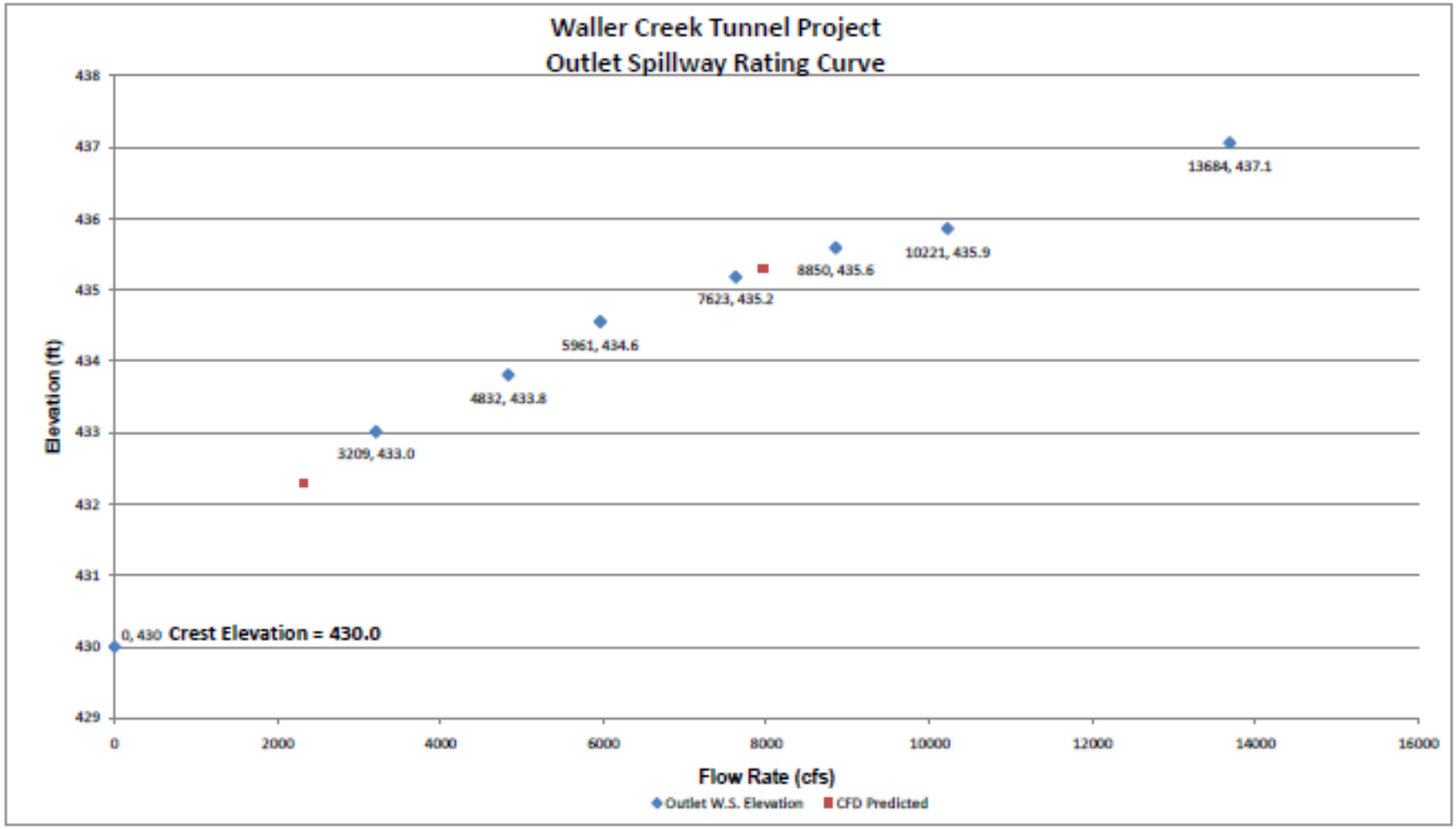
Testing
Lateral Junction Loss Coefficients

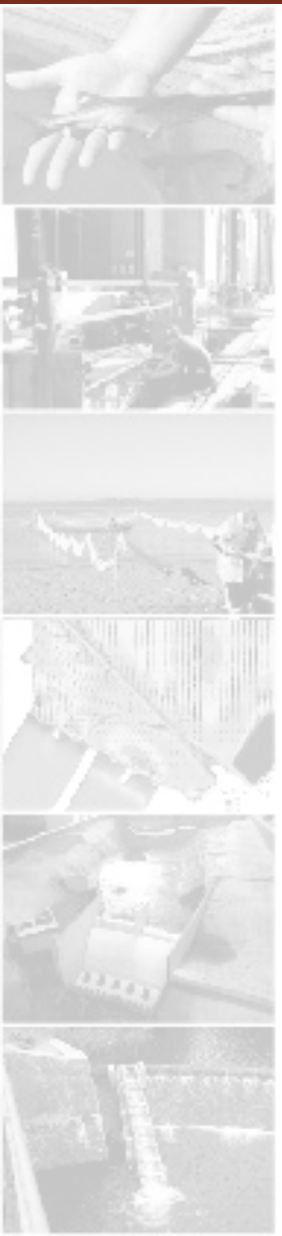
	100 yr Peak Tunnel-Peak Int.		*100 yr Lagging Tunnel-Peak Int.*	
Loss Coefficient	*8th St*	*4th St*	*8th St*	*4th St*
K_{2-3}	*0.3*	*0.2*	*0.3*	*0.3*
K_{1-3}	*-0.6*	*-0.7*	*-0.4*	*-0.4*

Testing
Outlet Spillway Rating Curve



Testing
Outlet Spillway Rating Curve





Questions??